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Smart Body Area Networks (SmartBAN) Unified data representation formats, semantic and open data model

Reference

DTS/SmartBAN-009

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Foreword

This Technical Specification (TS) has been produced by ETSI Technical Committee Smart Body Area Network (SmartBAN).

Modal verbs terminology

In the present document "**shall**", "**shall not**", "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the [ETSI Drafting Rules](#) (Verbal forms for the expression of provisions).

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1 Scope

The present document specifies and formalizes SmartBAN unified data representation formats (including in particular sensor/actuator/relay/coordinator/Hub descriptions and sensed/measured data), semantic open data model and corresponding ontology.

The present document is applicable to a BAN and/or a Smart BAN comprising wearable sensors/actuators devices, a relay/coordinator device and a Hub. The relay/Coordinator and the Hub functionalities may be handled by a single device or by two distinct devices.

The present document does not yet address the specification and the formalization of the SmartBAN service ontology and associated enablers. This will be addressed in the future release of the present document.

2 References

2.1 Normative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the reference document (including any amendments) applies.

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The following referenced documents are necessary for the application of the present document.

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3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

example 1: text used to clarify abstract rules by applying them literally

3.2 Symbols

For the purposes of the present document, the following symbols apply:

s	second
bps	bit per second
bpm	beats per minute

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

ANP	Alert Notification Profile
ASTM	American Standards for Testing and Materials
BAN	Body Area Network
CCR	Continuity of Care Record
CCU	Central Control Unit
CEN	European Committee for Standardisation
CESN	Coastal Environmental Sensor Networks
CRS	Coordinate Reference Systems
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DL	Description Logic
ECG	Electrocardiogram
EDAM	Embrace Data and Methods
EEG	Electroencephalogram
EHR	Electronic Health Record
GAP	Generic Access Profile
GATT	Generic Attribute Profile
GPS	Global Positioning System
GW	Gateway
HID	Human Interface Device
HL7	Health Industry Level 7
HOGP	HID Over GATT Profile

HR	Heart Rate
IC-ISM	Intelligence Community Information Security Marking
ICT	Information and Communications Technology
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
ISM	Industrial, Scientific and Medical
JSON	JavaScript Object Notation
KB	Knowledge Base
LAN	Local Area Network
LE	Low Energy
LSDIS	Large Scale Distributed Information Systems
MAC	Media Access Control
MBAN	Medical Body Area Network
MIPS	Microprocessor without Interlocked Pipeline Stages
MMI	Marine Metadata Interoperability
NoSQL	Not only SQL
NT	Node Type
O&M	Observations & Measurements
OGC	Open Geospatial Consortium
OpenGIS	Open Geospatial Consortium
OSI	Open Systems Interconnection
OUI	Organizationally Unique Identifier
OWL	Web Ontology Language
OWL DL	Web Ontology Language Description Logic
PDA	Personal Digital Assistant
PER	Packet Error Rate
PHD	Personal Health Device
PHY	Physical layer
RAM	Random Access Memory
ROM	Read-Only Memory
RTLS	Real Time Location Services
SDO	Sleep Domain Ontology
SEEK	Science Environment for Ecological Knowledge
SensorML	Sensor Model Language
SIG	Special Interest Group
SPARQL	SPARQL Query Language
SPP	Scan Parameters Profile
SQL	Structured Query Language
SSN	Semantic Sensor Network
SUMO	Suggested Upper Merged Ontology
SWAMO	Sensor Web for Autonomous Mission Operations
SWE	Sensor Web Enablement
TBD	To Be Defined
TC	Technical Committee
TTL	Time to Live
UML	Unified Modeling Language
US	United States
UUID	Universally Unique Identifier
UWB	Ultra Wide Band
W3C	World Wide Web Consortium
WBAN	Wireless Body Area Network
WBANID	Wireless Body Area Network Identifier
WSN	Wireless Sensor Network
WSNs	Wireless Sensor Networks
WSSN	Wireless Semantic Sensor Network
XML	Extensible Markup Language
YAML	Yet Another Markup Language

4 Introduction

The present document gives the high level description of a unified data format providing one of the building blocks for heterogeneity management in Smart BANs. The present document will in particular define a unified description model with an extensible semantic metadata for Smart BAN entities related data as well as for monitoring and control information. The corresponding metadata management and indexing framework will also be investigated.

5 Ambit and induced constraints

The scope of clause 5 of the present document is to briefly investigate the initial TC SmartBAN use case requirements in order to point out their impact on ETSI TS 103 378 specifications and designs. The initial additional requirements induced by ETSI TS 103 378 scenario will also be listed.

Wireless Body Area Networks (WBANs) are made of a collection of low-power embedded devices, mainly sensors or actuators that are used for monitoring vital data of a human and its environment (but not limited to human). Those embedded devices are located in the vicinity or on or inside the body, and are mainly provided with short range communication technologies. BANs are short distance networks of maximum 6 m³ that contain maximum 6 networks per m² and maximum 256 nodes per network [i.1]. These nodes may be mobile and the network topology may change frequently. The data rate of sensed data can actually vary from 75,9 kbps to 15,6 Mbps [i.1]. WBANs are not expected to be operated in licensed frequency bands. Hence, the frequency spectrum of operation will be in the unregulated frequency bands for industrial, scientific and medical (ISM) applications. If ISM and MBAN bands (US and European) with frequency between 2,3 GHz and 2,5 GHz are initially considered within TC SmartBAN, higher frequency bands (from 3,2 to 10,2 GHz) will also be considered for allowing the support of Real Time Location Services (RTLs). Finally, WBANs are characterized by strong constraints in terms of low power, low latency, low Packet Error Rate (PER), reliability, QoS, coexistence and security. The initial technical requirements retained by TC SmartBAN for WBAN parameters are listed in table 1.

Table 1

Parameter	Smart BAN Requirements
Coexistence/robustness	Good (low interference to other systems, high tolerance to interference)
Data rates (Sensor)	Nominally < 100 kbps/node (vital sign monitoring)
Transmission rate (PHY)	Up to 1 Mbps
Network topology	Star network
Power consumption (node)	TBD
QoS control	Priority based control and cross layer optimization. Emergency signal transmission supported.
Reliability	Robust to shadowing and multipath interference
Max. node capacity	up to 16 nodes (typically 8)
Range	< 1,5 m
Latency	< 125 ms (high sampling applications e.g. ECG, EEG.)
Security / privacy	TBD

The initial ambit envisioned by TC SmartBAN contributors is a BAN network organized around a Hub and mainly following a star topology. The Hub play the role of the BAN cluster head and also serves as an intermediary Gateway (GW) node allowing the interconnection of the BAN cluster with an healthcare local/remote monitoring and control centre. This node, with extended memory and processing capacity (e.g. a smart phone), should be responsible for all the heavy processing management and control operations of the SmartBAN. In case of a multi hop routing strategy, the BAN shall be provided with at least a bridge/relay functionality that could be handle by the SmartBAN's Hub or within a dedicated SmartBAN device. This relay/bridge device offers enhanced performance and robustness (e.g. relay around hidden devices), as well as optimized SmartBAN solutions with enhanced connectivity (multi-radio) and routing (multi-hop) capabilities. In some global healthcare architectures, the BAN's Hub role may sometimes be handled by a cluster-external intermediary node called Central Control Unit (CCU) [i.2]. Finally, BAN discovery functionality and interworking shall be handled and shall thus be taken into consideration for the specification of the SmartBAN semantic open data model. Figure 1 gives a simple example of the considered SmartBAN end-to-end architecture.

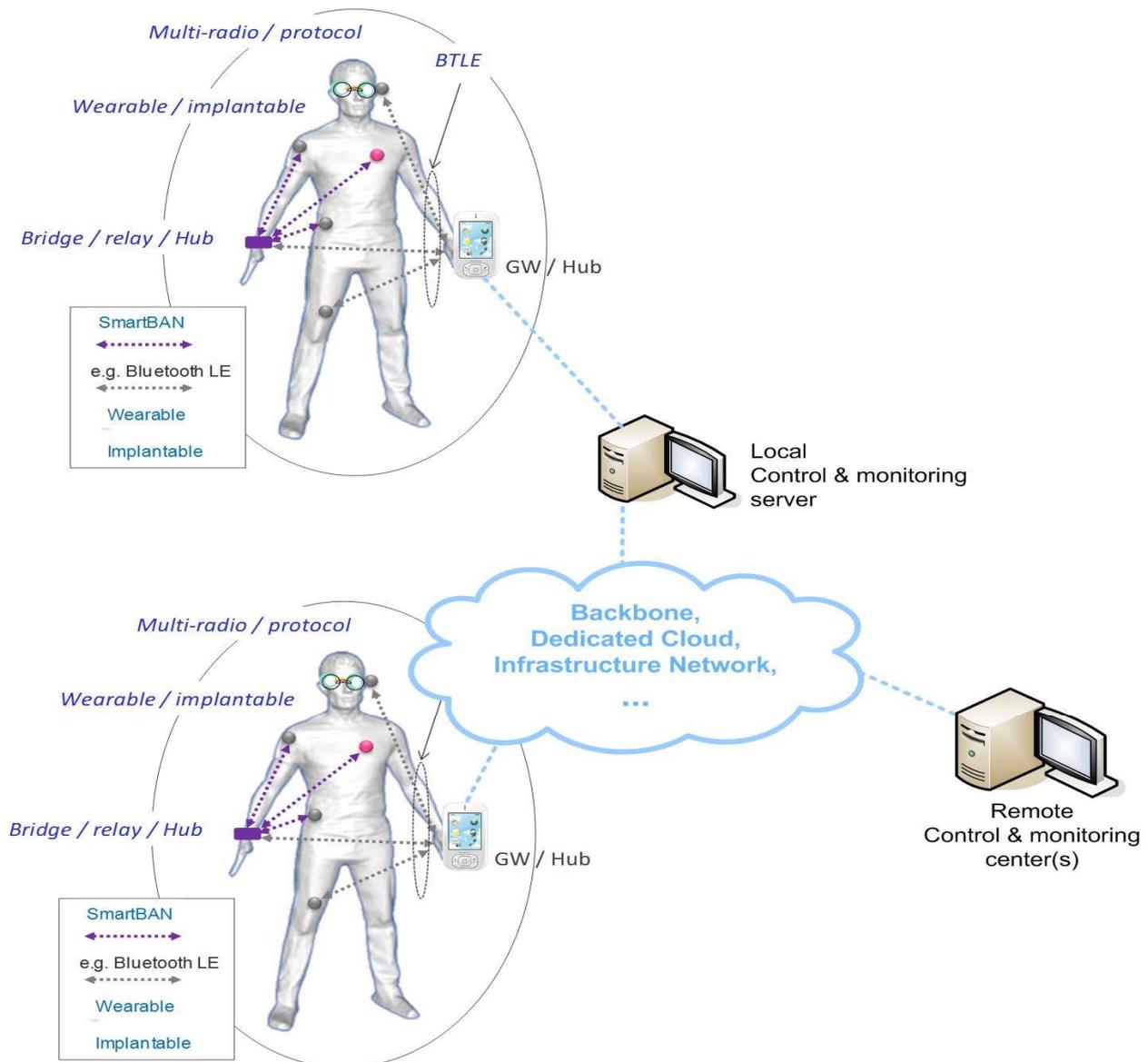


Figure 1: Example of considered SmartBAN end-to-end architecture

One main objective of the present document is the BAN heterogeneity management through the specification of a generic sensor and sensor data description and transfer format. This description format shall be as rich as possible to allow e.g. conflict resolution or similarity detection, but shall also be handled with low processing, low power and in quasi real time (e.g. latency < 125 ms and node addition or removal time < 3 s [i.1]). In that context, two scenarios shall a priori be envisioned:

- Or the proposed ontology is sufficiently light for allowing the sensor raw data pre-processing within the sensor itself,
- Or the pre-processing is deported to most powerful BAN's nodes. In that case, aforementioned nodes such as the BAN Hub or the BAN coordinator seem a priori good candidates for handling that pre-processing.

Furthermore, the ontology pre-processing and processing operations complexity strongly depend on the ontology format and storage format used (e.g. NoSQL [i.3] compared to SQL, or -YAML [i.4], JavaScript Object Notation [i.5], Extract Load Transfer strategies and Avro Schemas [i.6], etc. - compared to in particular XML, could significantly reduce the processing power required).

The aforementioned issues will be addressed in the present document.

6 SmartBAN open data model and ontology

6.1 SmartBAN information analysis

The objective of clause 6.1 of the present document is first to perform information analysis of the SmartBAN scenarios and to identify:

- the relevant related information sources, types, formats and owners;
- the information processing operations and functionality towards the SmartBAN related information.

Then, based on the analysis of existing information models already investigated in the SoA clause (see clause A.1 of the present document), the SmartBAN information meta-model (UML diagram) will be defined in clause 6.1 of the present document.

Dealing with tiny devices in WBAN shall lead towards the design of a modular model where some classes should be implemented in the sensor/actuator nodes depending on its resource's availability, and some others should be implemented and processed in more capable nodes like e.g. the SmartBAN' Hub or coordinator. Basically, the SmartBAN open data model shall be divided into three main parts: WBAN (SmartBAN or BAN cluster in the TC SmartBAN context), Nodes (i.e. Hub, sensors, actuators, etc.), Process and Measurements. Figure 2 depicts the class diagram that shall be introduced for the WBAN/Smart BAN.

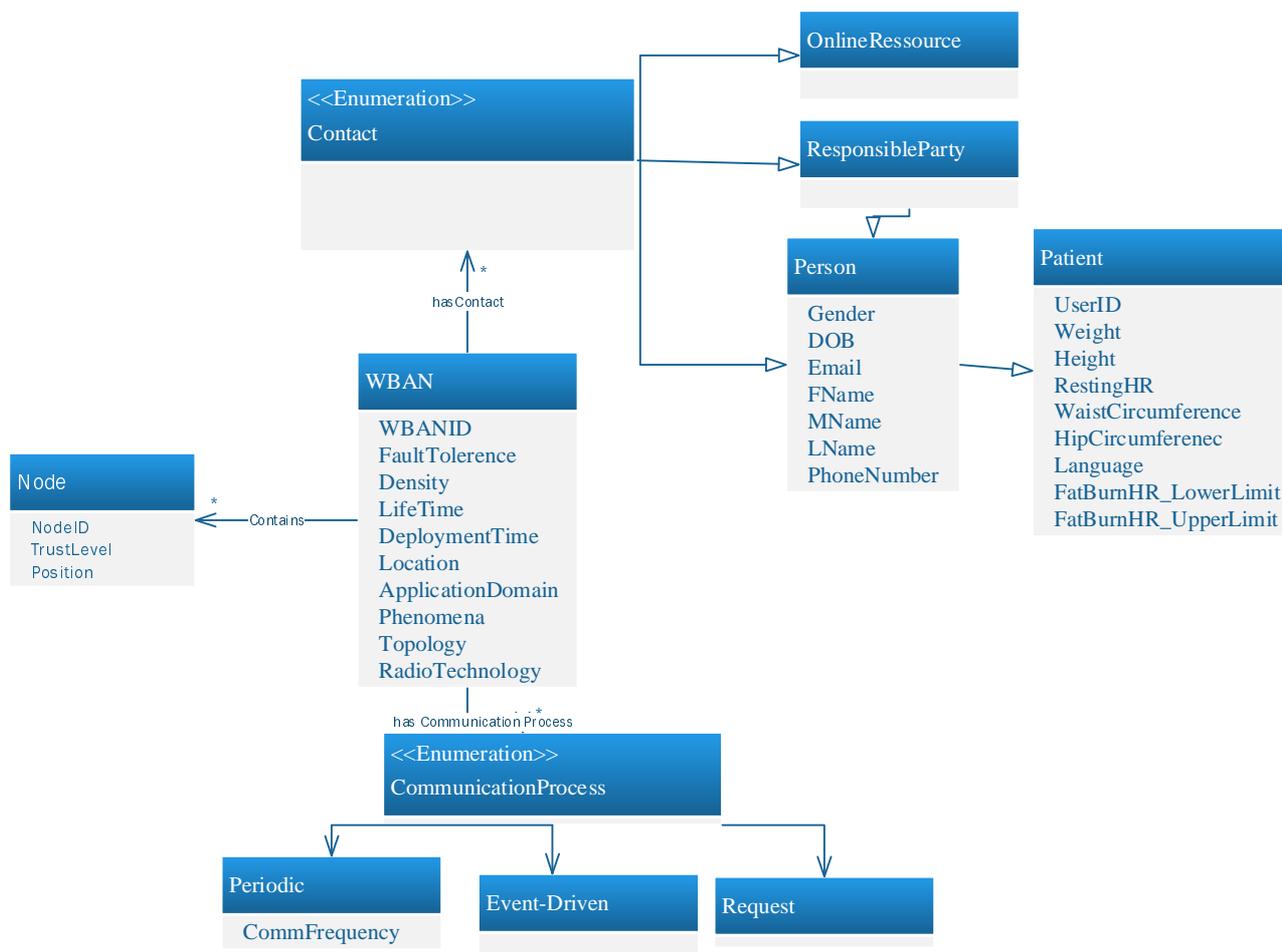


Figure 2: UML classes - TCSmartBAN_WBAN

First, a WBAN shall be identified by its WBANID that shall be unique (e.g. the 8-bit BAN ID defined within the TC SmartBAN MAC TS [1]) and accessible by any authorized user. It is deployed on the human body or implanted in the human body. Thus, the location of the WBAN, when available and needed, shall be given relatively to the one of the human body can refer to the location of the patient wearing the WBAN. The WBAN will monitor a specific phenomenon (burned calories during exercises, glucose level, etc.) belonging to a specific domain of application (healthcare, telemedicine, assisted living, sport training, pervasive computing, safety and emergency, etc.). The WBAN is composed of certain number of nodes (WBAN's density). These nodes are distributed based on a physical topology (star in the special case of SmartBANs). The required lifetime and the fault tolerance differ from one application to another. Whereas WBAN for entertainment purposes should have a lifetime of weeks or few years, WBAN dedicated for assisted living or anomaly monitoring should last for many years. In addition a WBAN shall measure accurate value and shall require a small fault tolerance. This parameter is essential in the management of the networks where the fault tolerance shall be respected and may imply nodes reconfiguration where some nodes are considered down due to the inaccurate sensed data. The data within the WBAN will be exchanged using in particular SmartBAN radio technology defined in ETSI TS 103 326 [2] and ETSI TS 103 325 [1].

Each WBAN shall have contacts, and this assumption still holds for SmartBANs. In SensorML model, a contact can be a person described by his name, userID, email and phone number. A contact can also be an organization described by its name and address. In our model, a contact shall be:

- An online resource or document, and in that case, a reference to the document is simply given as the class attribute.
- Or a Responsible Party which plays the role of the patient's reference. It should be an organization or a person. The creation of the responsible party is very useful for emergency cases. For example, if the WBAN is developed for the monitoring of elderly, in urgent cases, the system can generate a notification and send it to the responsible party's mobile phone.
- Or a person which may be a Patient. In the context of TC SmartBAN, the WBAN may have as contact one patient. The Continua[®] Alliance (see note), (see clause A.1.2.3 of the present document), describes the patient information in the user data service within the Bluetooth LE standard by patient's full name, weight, height, email, date of birth, gender, resting heart rate, waist circumference, hip circumference, fat burn heart rate lower limit, fat burn heart rate upper limit and language (these patient's data shall be added to the patient's attributes of the SmartBAN open data model). In order to enhance the management of electronic health data shared between medical systems, the diseases, blood type, allergy or any other medical descriptions shall be added to this information. The patient shall also be identified by a unique ID that may be his user ID or social security number. Sharing these data among different biomedical systems allow any clinic or hospital to identify the patient and deduce his medical archive.

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Whereas the WBAN can be formed by many clusters, the present document is focused on the topology shown in figure 1 where a SmartBAN shall be formed of only one cluster. This work can be extended to multi cluster topology where the cluster shall be identified by the Cluster ID. If Bluetooth LE is used for wireless communication, the channel for each cluster shall be saved in addition to the number of nodes and the topology used within the cluster. Finally, the SmartBAN shall contain nodes.

In WBAN architecture, three types of communication shall be differentiated: Intra WBAN communication between the nodes and the Hub, Inter WBAN communication between the Hub and the internet and beyond WBAN communication with the medical servers and health care systems on e.g. a cloud. The inter WBAN communication shall obey to one of these three ways. The first type is the periodic communication where the nodes send data to the BAN coordinator (i.e. the cluster Hub) every T seconds. The second one is based on BAN coordinator requesting BAN nodes for triggering their reply. The third one is based on event-triggering. When certain events occur, the nodes send their data to the BAN coordinator. That is why the inter WBAN communication type shall be precised to enhance remote management. For example, if periodic exchange is used, and the hub did not receive data during T seconds, it should identify that this node is malfunctioning.

The description of the SmartBAN node's model is now presented. Figure 3 represents the UML class diagram that shall at least be specified for the SmartBAN's nodes. The node shall be a sensor, an actuator which acts according to data received from the sensors or through interaction with user, or a node responsible of data routing or pre-processing like a BAN coordinator or relay, a cluster head (BAN's hub), or others. As an example, an actuator equipped with a built-in reservoir and pump can administer the correct dose of insulin to give to diabetics based on the glucose level measurements. The node may be a cluster head (BAN's hub) which is responsible for collecting the data and for sending it outside the WBAN to a local or remote monitoring and control centre. In some cases, the coordinator is called aggregator, collector or body centre unit. In the SmartBAN model, the coordinator is called the Hub. In many cases especially in m-health applications, the Smart Phone or the PDA of the user will play this role. It will collect the data from the sensors via Bluetooth interfaces and send it to the medical servers via 3G/4G or wireless interfaces.

Moreover, each node shall be identified by the Node ID that may be the MAC address, the serial number or any other unique descriptor. A new class named "NodeType" and describing the physical characteristics of a node (as described in the SoA clause A.1.1.2 of the present document) has been introduced within the SmartBAN data model for redundancy avoidance. Each node shall have only one node's type. The survival properties, which describe the conditions to which a sensor can be exposed without causing lasting damage, shall also be added. When these properties occurred on a network, all data sent from this node should be considered as insignificant data and trigger the stopping of this node.

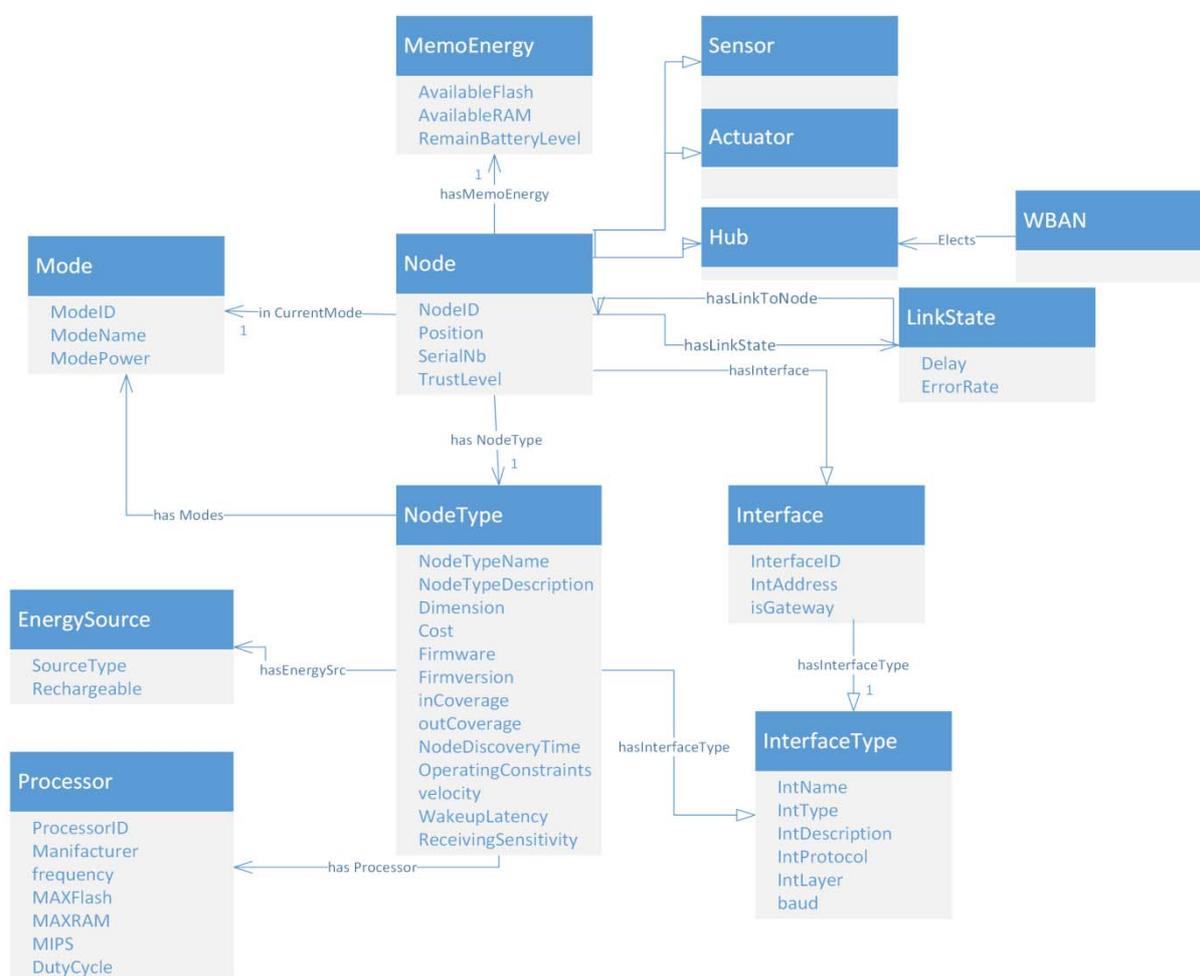


Figure 3: UML Class Diagram- Nodes

The mobility also enhances the performance of the sensor networks. Basically, the nodes in WBAN have mobility capability. Thus, the velocity of a mobile sensor, the energy consumption during its movement and the maximum distance that it can travel should be registered in the SmartBAN node model. This feature will help in collecting data. Many times it will be more efficient for the network that a mobile sensor travels over the network to collect data or send request or reconfigure certain nodes. Each node type has certain functioning modes (Sleep, active, down, transmission, reception, etc.). Keeping in mind the power management of the WBAN (SmartBAN low energy constraint), the power consumed in each mode will help us in estimating the lifetime of the WBAN and shall be registered in the SmartBAN node model. For example, if the communication within the WBAN is a periodic communication, it will be useful to switch the node from active mode to sleep mode during a period t (since no data will be sent during that period), thus permitting a reduction of power consumption on the node.

Each node type shall have wakeup latency. The wakeup latency is the time required by the sensor to generate a correct value once activated. Clearly, if the sensor reading is performed before the wakeup latency has elapsed, the acquired data is not valid. Furthermore, each node type shall have a processor identified by a processor ID. The processor shall have RAM, ROM and a flash memory. The node with higher memory resources has the priority to be elected as cluster head or a BAN coordinator. In addition, the MIPS, frequency and duty cycle shall be introduced in the SmartBAN node model because they reflect the speed of processing certain data.

While the nodes are typically powered by batteries with a limited lifetime, they should benefit from additional energy harvested from the external environment. Recently, many researches have been investigated in the domain of energy scavenging from on-body sources such body heat and body vibration. Where the source of energy for the same node can vary, the source of energy shall be revealed in the SmartBAN open data model.

Data transmissions within a WBAN are via interfaces. Each node type may have many interfaces (e.g. SmartBAN PHY & MAC TS, Bluetooth, UWB, IEEE 802.15.6 [i.7], serial interface, etc.). A new class "interface type" that describes the standard characteristics of the interface's protocol, the baud rate and the functional layer shall be added for redundancy avoidance. Regarding the interface, it shall be identified by the interface ID that may be the IP address or the unique address used in the communication protocol. The interface may have many addresses like MAC address, IP address or others. One shall precise if the interface is considered as gateway in order to help the monitoring and control server in finding how it can communicate with the WBAN from its LAN, backbone, or infrastructure side.

The dynamic characteristics of a node that vary during the WBAN lifetime are now presented. First, each node shall have only one current mode. For example, if a BAN coordinator has sent a request to collect certain information, only nodes who are in Active mode can reply. Moreover, the patient's information shall be always available to the physician. By tracking the current mode of each node, in addition to the features mentioned before, one may choose how the switching process shall be done. The node occupies certain position, it can be planted in the human body, on the body surface (head, waist, chest, wrist, etc.), or not in contact with the human body with a distance of few meters [i.1].

Moreover, security is a key point in WBAN management, that is why the Trust Level for each node shall be added within the SmartBAN data model.

The dynamic memory and energy components of the nodes shall be described in the "MemoEnergy" class. The remaining lifetime or memory may influence directly on the selection of the BAN Hub or coordinator, especially that the hub's death may cause the malfunctioning of the entire WBAN.

Finally, a crucial issue is the reliability of the transmission in order to guarantee that the monitored data is received correctly and in reasonable time. In general, the Hub is the node who can monitor other nodes to predict any failure. To assure the reliability, the link state for the path between nodes shall be added to the SmartBAN data model for indicating the last time the Hub has received a message from a node. If this time is too long, the Hub can therefore predict that this node is facing some trouble. In addition, it will keep track of the error rate of a node and its delay to consider a node as invalid and asks it to go to the inactive mode in order to reduce bandwidth consumption.

The third parts of the SmartBAN open data model shall be provided with the process classes presented in Figure 4.

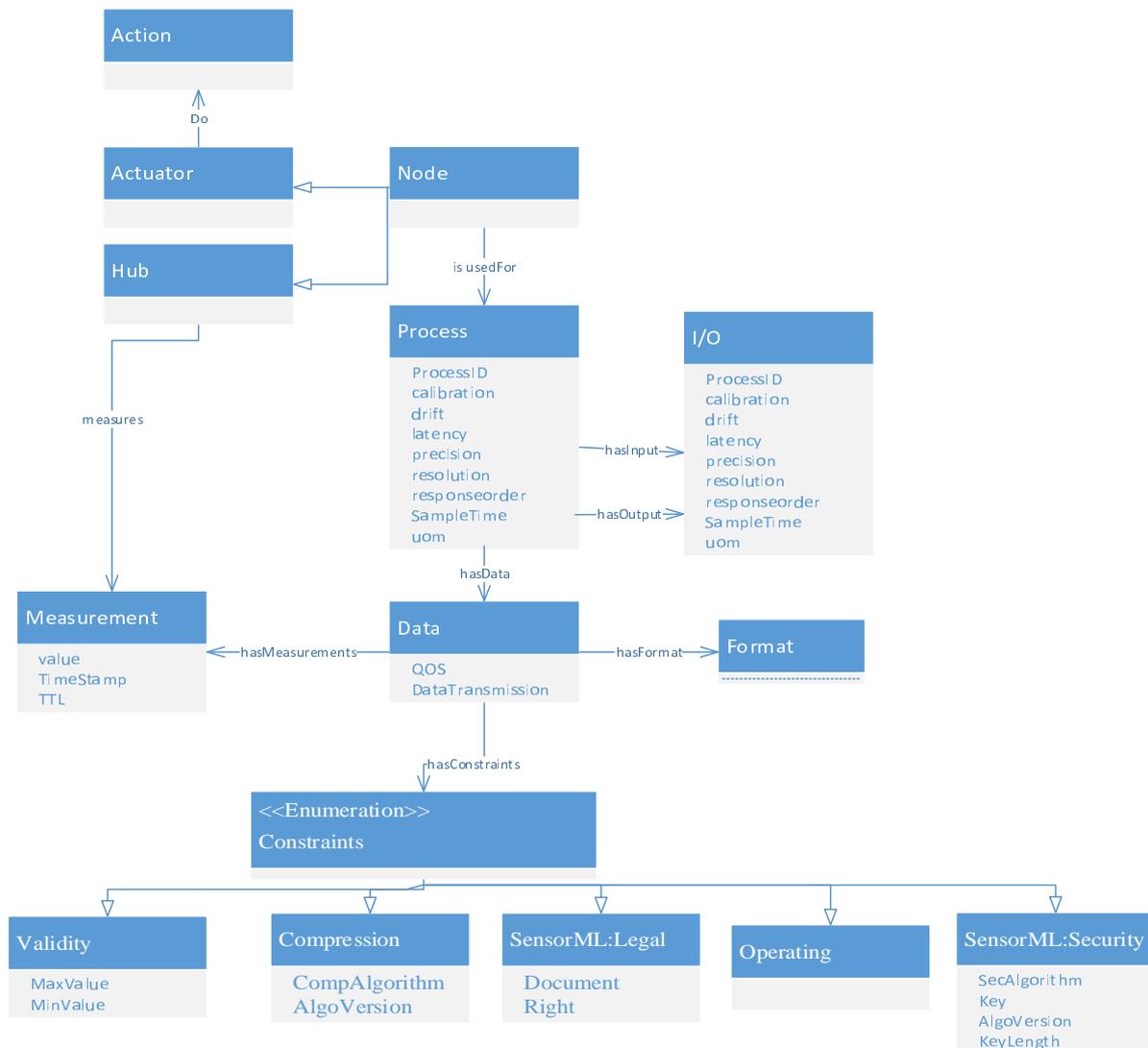


Figure 4: UML Class Diagram- Process & Measurements

Each node is used for certain process (temperature, blood pressure, insulin regulation, etc.). While sensors measure some measurements, actuators do certain actions. Based on the survey done in the survey clause A.1.1 of the present document, the following properties shall be added to the process class that shall be introduced to the SmartBAN open data model: calibration, precision, response order, drift, unit of measurement, latency, resolution and data rate. These parameters enhance the cooperation between different WBAN measuring the same process. For example, if one is monitoring the temperature, regardless the sensor's physical characteristics, the data rate should be around 120 bps with a precision of 8 bits. In addition, these parameters may help in the management of the access to the medium. If a process is characterized by a small latency, it should be given a higher priority to access the medium and send the data to the Hub. Moreover, the process shall have one or many data. For example, the tracking process shall include latitude, longitude and speed data. Many recent researches have been investigated to describe the electronic health data. As one can see in the survey clause A.1.2 of the present document, some models are dedicated for services discovery like GATT profiles, others focused on the interoperability between different medical centres and clinical centres. The present document is concentrated on the data sent within the BAN and sent from the Hub to an external medical control and monitoring server.

EDAM (EMBRACE Data and Methods) [i.8] is a data model of bioinformatics operations (tool, application, or workflow functions), types of data, topics (application domains), and data formats. The applications of EDAM are within organizing tools and data, finding suitable tools in catalogues, and integrating them into complex applications or workflows. EDAM includes 4 main sub-ontologies of concepts:

- **Operation:** A function or process performed by a tool; what is done, but not (typically) how or in what context.
- **Data:** A type of data in common use in bioinformatics.

- **Topic:** A general bioinformatics subject or category, such as a field of study, data, processing, analysis or technology.
- **Format:** A specific layout for encoding a specific type of data in a computer file or message.

EDAM may be used in the proposed SmartBAN data model, in particular in case where the biomedical sensors are used for bioinformatics data, for example in the analysis of mutations in cancer. In such application, the process shall have as data the data class in EDAM.

WBANs are widely used for remote patient monitoring and non-medical applications. That is why other existing models that describe the data types sensed by biomedical nodes have to be searched. As shown in the survey clause A.1.2.3 of the present document and in the reference model of the electronic healthcare, the data types include all the biomedical data formats. Whereas the process shall have one or many data, the data shall have one data format or type as described in the data value of the reference model. Moreover, three properties shall be added to the data class of the SmartBAN model: QoS, Data size and Data transmission. The data size reflects the precision and the resolution of the sensed data. In addition, WBANs are characterized by heterogeneous data that differs in their data rate, bandwidth, data types, accuracy, delay and others. An effective QoS mechanism is needed in order to deliver adequately these various information [i.1] and [i.2]. Beside QoS, data transmission should be unicast, multicast or broadcast. In general, it is considered as multicast when it is sent to group of nodes within a cluster and as broadcast when it is sent to the entire active nodes in WBAN. If the remaining lifetime of a node is crucial, it can ignore a broadcast or multicast data to save power.

In addition, the data shall have constraints. In SensorML, data can be constrained by security constraints based on the Security Banner Marking model of the Intelligence Community Information Security Marking (IC-ISM) Standard, valid Time that describes the validity time for certain process, and legal constraints which can be a private Act, intellectual Property, rights or copyrights. Those constraints shall be reflected in the SmartBAN data model. Moreover, in the GATT service profiles, each data is described by its minimum value and maximum value and those values shall be part of the Validity class. Furthermore, a data may have operational constraints. Consequently, the constraints shall at least be legal constraint, validity constraints (having minimum and maximum values), operational constraints, security constraint (security protocol and used key or certificate's reference), and compression constraint (compression algorithm).

Finally, a light class to store the measurements done by the sensors shall be added to the SmartBAN open data model. One of the main goals of this class is to be implemented within the sensor without affecting its performance permitting data aggregation and data value verification within the node before sending the data to the Hub. It shall include the sensed value, the timestamp and may include TTL (Time to Live) in order to assure the freshness of the medical data. In that way, if the connection to the hub is temporary unavailable, the sensor can check for the freshness of the sensed data, and if it is expired the data will not be sent to the Hub. Due to the limited resources of the sensors in terms of processor and memory, only this part of the model should be processed by the sensors allowing the conversion from raw data to aggregated data when it is necessary. For example, if only the average heart rate of a patient is needed to calculate the number of burned calories, this calculation may be done by the sensor and sent to the hub without degrading the performance of the node.

6.2 SmartBAN open data model ontology

6.2.0 Introduction

One of the most important problems in electronic health is data heterogeneity management and interoperability between different systems. Two types of interoperability can be differentiated:

- 1) **Syntactic and structural interoperability:** the structure and provenance of information is understood by any clinical system.
- 2) **Semantic Interoperability:** having a common understanding of the information and data sources semantic such that they could be interpreted in a unique way by different clinical systems.

In order to ensure this SmartBAN interoperability and heterogeneity management, a dedicated open data model was already introduced and conceptualized in clause 6.1 of the present document (in the form of UML class diagrams). This open data model concept shall now be fully formalized and implemented through the use of ontology and this is the objective of clause 6.2 of the present document.

Therefore, a SmartBAN-dedicated ontology shall be formalized and developed based on the meta-model defined in clause 6.1. This BAN ontology, fully specified and presented in clause 6.2 of the present document, shall be designed in a way that existing healthcare and telemedicine data/information models and standards can be utilized through it (i.e. this SmartBAN ontology) for developing smarter control and monitoring operations as well as standardized eHealth services.

Ontology Web Language (OWL) has first been retained as description language for the formalization and the implementation of the computer interpretable SmartBAN-dedicated semantic ontology. This OWL-based ontology will allow the unique interpreting of different data, information and terms coming from different biomedical devices, applications and vendors. OWL DL, the lighter version of OWL, offers decidability by allowing consistency checking and automatic reasoning on the knowledge base using realistic computing resources in a reasonable time. Advanced rules may be assigned to the ontology to infer particular information based on the domain's requirements. Basic ontological components are classes, which are the sets of individuals with common characteristics, individuals which are specified objects in the domain and properties used to state relationships between individuals or from individuals to data values.

OWL DL offers the following options when defining a new class:

- subclass of;
- equivalent to;
- disjoint with;
- min cardinality;
- max cardinality.

Moreover, when creating an object property (which is the relation between two classes), the domain and the range shall be indicated and one can precise if it is:

- functional or inverse functional;
- transitive;
- inverse of;
- symmetric or asymmetric;
- reflexive or irreflexive.

Regarding the data property, the domain and the range (integer, string, anyURI, etc.) shall be precised. The data property may be functional, equivalent or disjoint from another data property.

The latest version of Protégé (4.3) has been used in the present document to formalize the SmartBAN semantic open data model and ontology for the following reasons:

- Mostly used
- Support RDF/OWL structure
- User friendly interface
- Can import existing ontologies
- Clear visualization of the classes and properties (OntoGraph plug-in)
- Support wide range of reasoners especially Pellet reasoner
- Support SWRL language
- Clear justification of the inferences

Benefiting from the properties in OWL DL, the SmartBAN dedicated ontology shall be created as follows. Firstly, the SmartBAN domain shall be split and represented with three different sub-ontologies: WBAN, Nodes and Process. Those sub-ontologies shall fully mirror the three main classes of the SmartBAN open data model concept (see clause 6.1 of the present document). The distribution and description of the classes shall also mirror the one that has already been described in the UML class diagrams presented in clause 6.1 of the present document. Furthermore, when defining the properties of each class, one noted that many properties are variables described by their value and unit of measurement (like e.g. frequency, weight, height, speed, etc.). This is why a new class Quantity, capable of generically defining any kinds of units, shall be introduced into the SmartBAN data model. QUDT was developed by NASA for that purpose and its last specification and version were released in April 2013 [3]. The already proposed models for managing hardware heterogeneity in wireless sensor network (see survey clause A.1.1.6 of the present document) also adopted QUDT ontology for units definition due to its wide adoption in many domains like e.g. e-commerce platform. Therefore, the Unit class from QUDT (Quantities, Units, Dimensions and Data Types) generic model [3] shall be adopted for the Quantity class. Figure 5 depicts a part of the hierarchy of the unit class. This hierarchy is also extensible for new units' type definitions.

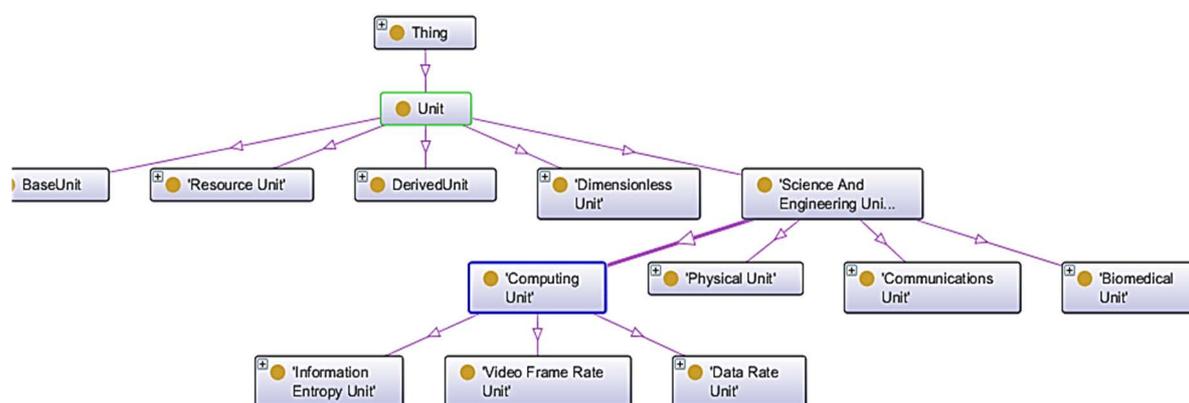


Figure 5: Part of the hierarchy of the QUDT unit class

So, each Quantity shall have as data property "hasvalue" of any type and has, as quantity, an individual of type Quantity.

The node's location is essential in WBAN where the sensor's position should be: implanted or inside body, body surface or external. The node's location shall then be added to the SmartBAN model and ontology. In addition, the WBAN's location shall also be added to the model. Therefore, a new class "Location" shall be introduced in the SmartBAN model and ontology for that purpose. This class shall have as subclasses:

- Implant: which can be under the skin or inside the human body.
- Body surface: which has as data properties the position of the node relatively to the human bod.
- External: this subclass should be used to express the location of the WBAN's Hub, or nodes built in the PDA or Mobile of the patient, or to describe the location of the WBAN. This location may be given as coordinates for example using the latitude and longitude, or given by an address (City, country, building, etc.) or others.

The use of Location as independent class gives the user the ability to extend it by importing existing ontologies dedicated for locations. Some of these ontologies are e.g.:

- Location.owl [i.9], an ontology to describe geographical and non geographical locations;
- The Places ontology [i.10], an ontology created by Smethurst, Styles and Scott for describing places of geographic interest.

Figure 6 shows the hierarchy of the Location class that shall be adopted for SmartBAN.

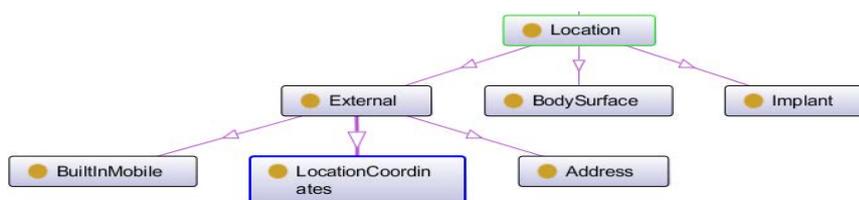


Figure 6: Classes hierarchy for Location class

The following clauses will now detail proposed SmartBAN ontology that shall be adopted, with all the classes introduced, their object's properties and their data properties.

6.2.1 WBAN ontology

Classes:

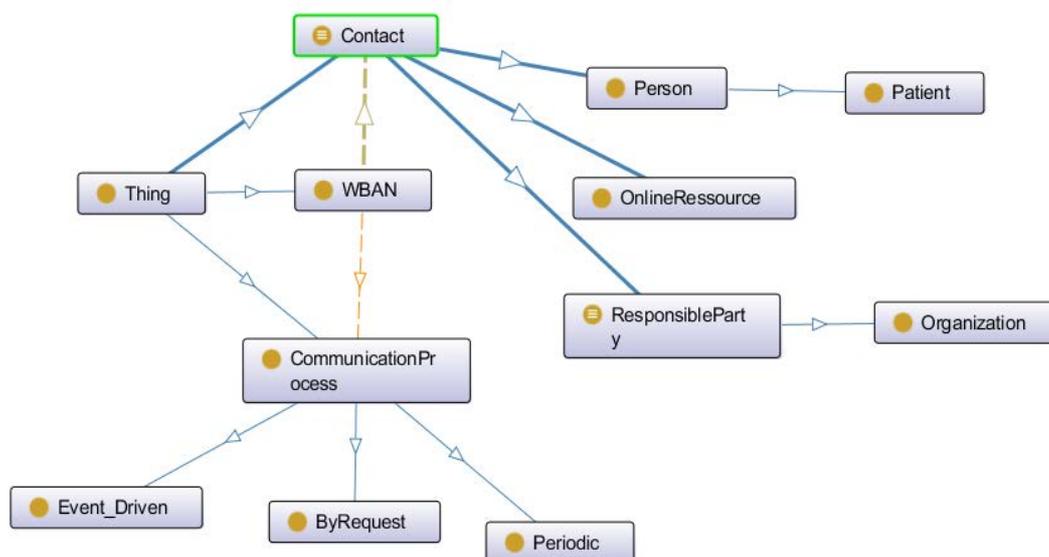


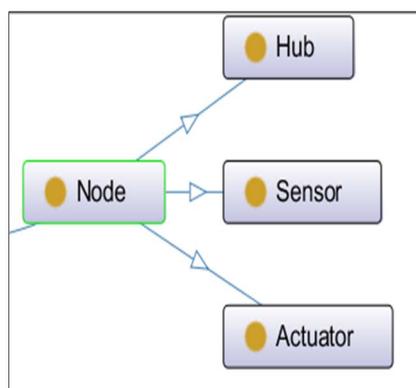
Figure 7: WBAN/SmartBAN Classes hierarchy

Object Properties:

Object property	Domain	Range
hasContact	WBAN	Contact
hasCommunicationProcess	WBAN	CommunicationProcess
CommunicationPeriod	Periodic	ontofull:Quantity
Height	Patient	ontofull:Quantity
Weight	Patient	ontofull:Quantity
HipCircumference	Patient	ontofull:Quantity
RestingHR	Patient	ontofull:Quantity
MaxHR	Patient	ontofull:Quantity
WaistCircumference	Patient	ontofull:Quantity

Data Properties:

Data Property	Domain	Range	Additional property
Age	Patient	int	<100
ApplicationDomain	WBAN	string	
Density	WBAN	string	
DeploymentTime	WBAN	dateTime	
Email	Person	string	
MaxFatBurnHR	Patient		
MinFatBurnHR	Patient		
FaultTolerance	WBAN	real	
Gender	Person	string	length 1
Language	Person	string	
Link	OnlineResource	anyURI	
Phenomena	WBAN	string	
Phone	Person or ResponsibleParty		
RadioTech	WBAN	string	
Topology	WBAN	{"Adhoc", "Stars", "Mesh", "Others"}	
UserID	Patient		
WBANID	WBAN	anyURI	Functional

6.2.2 Nodes ontology**Classes:****Figure 8: Node's subclasses**

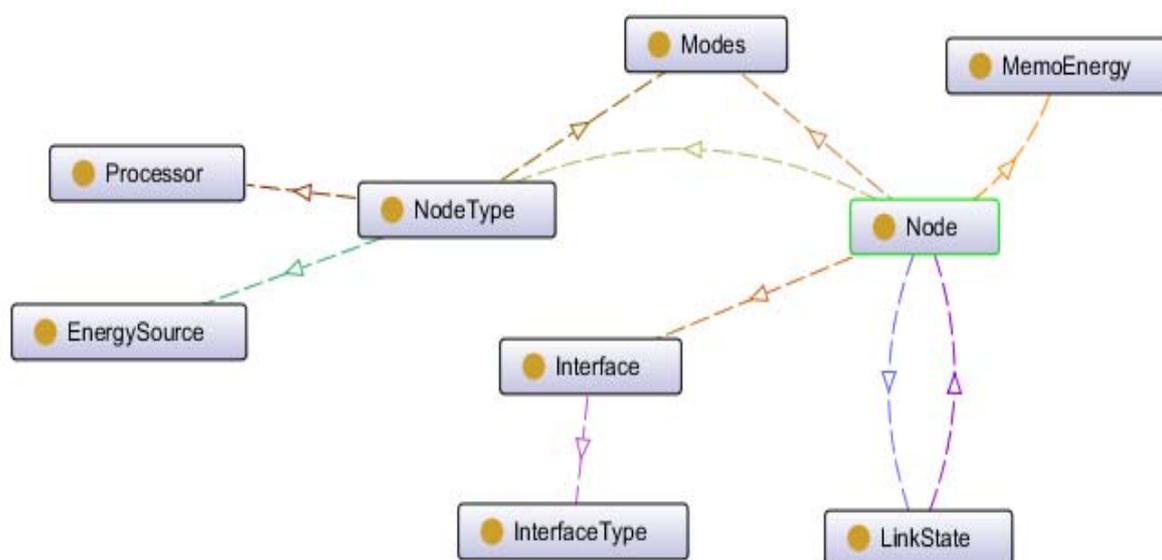


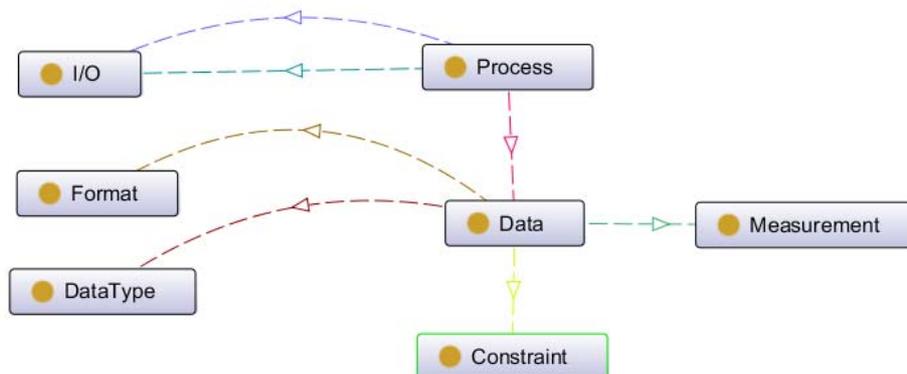
Figure 9: Nodes Classes relationships

Object Properties:

Object property	Domain	Range	Cardinality	
			min	max
cost	NodeType	ontofull:Quantity		1
dimension	NodeType	ontofull:Quantity		4
DutyCycle	Processor	ontofull:Quantity		1
frequency	Processor	ontofull:Quantity		1
hasAvailableFlash	MemoEnergy	ontofull:Quantity		1
hasAvailableRAM	MemoEnergy	ontofull:Quantity		1
hasEnergySrc	NodeType	EnergySource		
hasInterface	Node	Interface		
hasInterfaceType	Interface	InterfaceType	1	1
hasLinkState	Node	LinkState		
hasLinkToNode	LinkState	Node		1
hasMAXFlash	Processor	ontofull:Quantity		1
hasMAXRAM	Processor	ontofull:Quantity		1
hasMemoEnergy	Node	MemoEnergy		1
hasModes	NodeType	Modes		
hasNodeType	Node	NodeType		1
hasProcessor	NodeType	Processor		
hasRemainBattery	MemoEnergy	ontofull:Quantity		1
inCoverage	NodeType	ontofull:Quantity		
inCurrentMode	Node	Modes	1	1
MIPS	Processor	ontofull:Quantity		1
ModePower	Mode	ontofull:Quantity		
NodeDiscoveryTime	NodeType	ontofull:Quantity		1
outCoverage	NodeType	ontofull:Quantity		
Position	Node	ontofull:Location		
receivingSensitivity	NodeType	ontofull:Quantity		1
velocity	NodeType	ontofull:Quantity		1
WakeupLatency	NodeType	ontofull:Quantity		1

Data Properties:

Data Property	Domain	Range	Additional property
InterfaceAdress	Interface		
Int_Type		string	SubProperty of InterfaceAddress
Int_value			SubProperty of InterfaceAddress
baud	InterfaceType		
delay	LinkState	float	
ErrorRate	LinkState	float	
Firmversion	NodeType	string	
Firmware	NodeType	string	
IntDescription	InterfaceType	string	
InterfaceID	Interface	anyURI	Functional
IntLayer	InterfaceType	string	
IntName	InterfaceType	string	
IntProtocol	InterfaceType	string	
isGateway	Interface	boolean	
ModeID	Mode	anyURI	Functional
ModeName	Mode	string	
NodeID	Node	anyURI	Functional
NodeTypeDescription	NodeType	string	
OperatingConstraints	NodeType	string	
ProcessorID	Processor	anyURI	Functional
Rechargeable	EnergySource	boolean	
SerailNb	Node	string	
SourceType	EnergySource	string	
TrustLevel	Node		

6.2.3 Process ontology**Classes:****Figure 10: Process class hierarchy**

Object Properties:

Object property	Domain	Range	Cardinality	
			min	max
calibration	Process	ontofull:Quantity		1
DataSize	Data	ontofull:Quantity		1
DoAction		Action		
drift	Process	ontofull:Quantity		
hasConstraints	Data	Constraints		
hasData	Process	Data		
hasDataType	Data	DataType		1
hasDerivedData	Process	Data		
hasFormat	Data	Format		1
hasInput	Process	I/O		
hasMeasurement	Data	Measurement		
hasOutput	Process	I/O		
latency	Process	ontofull:Quantity		1
precision	Process	ontofull:Quantity		1
resolution	Process	ontofull:Quantity		1
responseorder	Process	ontofull:Quantity		1
SampleRate	Process	ontofull:Quantity		1
Uom	Process	Unit		1

Data Properties:

Data Property	Domain	Range	Additional property
AlgorithmVersion	Compression or Security	string	
CompAlgorithm	Compression	string	
Key	Security	string	
KeyLength	Security	int	
MaxValue	Validity		
MinValue	Validity		
ProcessID	Process	anyURI	Functional
QOS	Data		
SecAlgorithm	Security	string	
TimeStamp	Measurement	dateTime	
TTL	Measurement	int	
valid	Measurement	boolean	
value	Measurement		

The valid data property shall be used to determine if the measurement is valid or invalid. For example:

- If the TTL is zero, which means that the measurement is not fresh,
- When the value of a measurement exceeds the maximum range,
- When the measurement is captured before the wakeup latency,
- etc.

In all these cases, the measurement should be invalid and not considered as correct value for further treatments.

6.2.4 Ontofull ontology

Ontofull ontology (see clause B.4 of the present document for the full OWL-DL specification) shall include four direct imported ontologies: wban.owl (see annex B of the present document for the full OWL-DL specification), nodes.owl (see clause B.2 of the present document for the full OWL-DL specification), process.owl (see clause B.3 of the present document for the full OWL-DL specification) and dimension.owl (which contains the unit classes as described by QUDT; this ontology will lead to an indirect import for the qudt.owl ontology).

Classes:

The Quantity class, the Unit class and subclasses shall be added to the WBAN/SmartBAN ontology, as already depicted in Figure 5 and Location class and subclasses shall also be added as already presented in Figure 6.

Object Properties:

Object property	Domain	Range	Cardinality		Additional property
			min	max	
BelongTo	Node	WBAN		1	inverse of Contains
Contains	WBAN	Node			inverse of BelongTo
DoAction	Actuator	Action			
ElectHub	WBAN	Hub		1	
hasUnit	Quantity	Unit			
isMeasuredBy	Measurement	Sensor		1	inverse of measures
measures	Sensor	Measurement	1		inverse of isMeasuredBy
usedFor	Node	Process	1		

Data Properties:

Data Property	Domain	Range	Additional property
hasValue	Quantity		

Rules:

Additional rules shall be added to the ontology based on the application domains of WBANs/SmartBANs. These rules are defined using Semantic Web Rule language SWRL [i.11] in the present document.

Rule 1: When a node measures some measurements having certain Data belonging to a process A, one should assume that this node is used for process A. the rule is:

- $\text{Node}(?N), \text{measures}(?N, ?M), \text{hasData}(?P, ?D), \text{hasMeasurement}(?D, ?M) \rightarrow \text{usedFor}(?N, ?P)$

Rule 2: When a WBAN/Smart BAN elects a Hub, one shall infer that this WBAN/Smart BAN contains the Hub.

- $\text{WBAN}(?W), \text{ElectHub}(?W, ?S) \rightarrow \text{Contains}(?W, ?S)$

Rule 3: If the WBAN/Smart BAN contains a sensor built in the mobile, and the WBAN/Smart BAN elects this mobile as Hub, one should assert that the sensor has the same node type as the mobile:

- $\text{WBAN}(?W), \text{Position}(?N, \text{BuiltInMobile}), \text{hasNodeType}(?S, ?NT), \text{Contains}(?W, ?N), \text{ElectHub}(?W, ?S) \rightarrow \text{hasNodeType}(?N, ?NT)$

Rule 4: If the TTL of a measurement is equal to zero, the measurement should be invalid.

- $\text{Measurement}(?M), \text{TTL}(?M, ?T), \text{equal}(?T, 0) \rightarrow \text{valid}(?M, \text{false})$

Rule 5: In the context of SmartBAN, the hub shall observe the link state of the nodes belonging to the same WBAN/Smart BAN of a certain patient. Thus, if a Hub has link state to a node, and this Hub belongs to a WBAN/Smart BAN, the node should belong to the same WBAN/Smart BAN.

- $\text{WBAN}(?W), \text{hasLinkState}(?S, ?L), \text{hasLinkToNode}(?L, ?N), \text{Contains}(?W, ?S) \rightarrow \text{Contains}(?W, ?N)$
- $\text{WBAN}(?W), \text{hasLinkState}(?S, ?L), \text{hasLinkToNode}(?L, ?N), \text{Contains}(?W, ?N) \rightarrow \text{Contains}(?W, ?S)$

The users of the SmartBAN ontology may define additional rules related to its application using the SWRL language. The general rules applicable for all types of WBAN/Smart BAN applications have only been defined/specified in the present document.

6.2.5 OWL-DL formalization of the SmartBAN ontology

This clause presents the OWL-DL formalization that shall have TC SmartBAN's WBAN ontology. Since all the ontology classes, objects and attributes were already fully detailed in the previous clauses of the present document, their corresponding text XML format will only be listed in Annex B of the present document.

6.3 SmartBAN ontology pre-validation

The objective of clause 6.3 of the present document is to present the first pre-validation tests of the SmartBAN ontology that have been conducted within TC SmartBAN. Mainly based on symbolic validation methods, those tests will demonstrate the a priori validity of the proposed SmartBAN ontology.

To pre-validate the ontology, the example of a WBAN equipped with a heart beat sensor and GPS receiver has been implemented for calculating the calories burned of a runner during exercises. A common used sensor has been used for heart beat measurements.

For testing purposes, two WBANs Runner_Fadi and Runner_Lina have been created as depicted in Figure 11. Because the WBANID is a functional property, each WBAN can have only one WBANID. That is why the MAC address of the mobile where the application is downloaded was chosen as WBANID, knowing that the application can be downloaded once on the mobile. The WBAN has contact the runner identified by his email address. In order to calculate the burned calories the runner should be described by his age, gender, height and weight. The WBAN contains the GPS and the heart beat sensors and elects the Mobile as Hub. Figure 12 depicts a part of Runner_Lina's WBAN ontology instance.

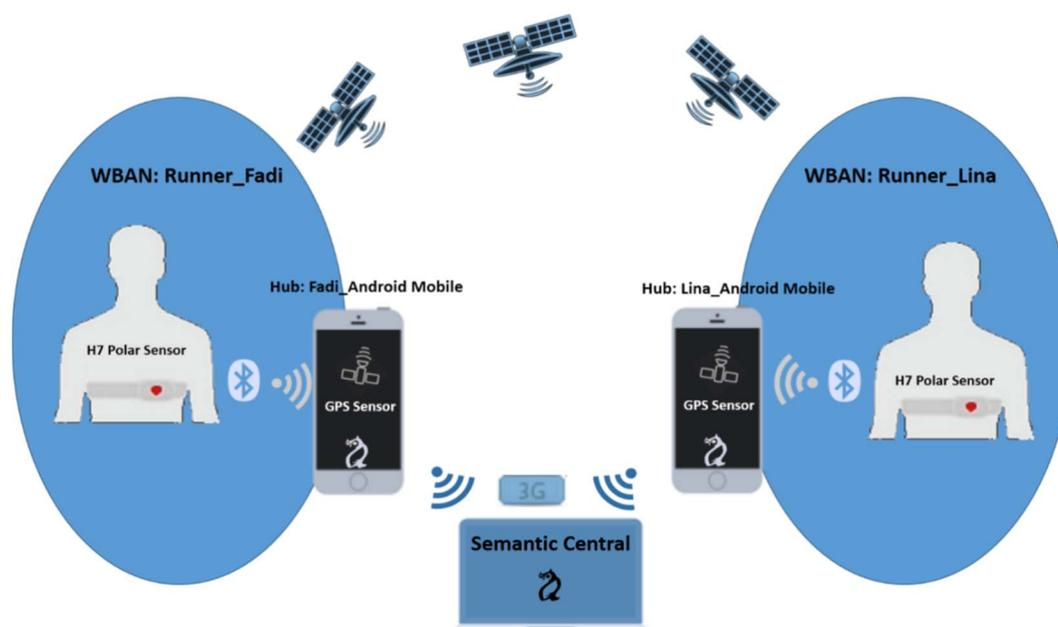


Figure 11: High-level architecture of the retained test scenario

The object property, "Contains Lina_AndroidMob" is inferred based on rule 2 defined in clause 6.2.4 of the present document.

The mobile phone is equipped with a Bluetooth LE interface and a 3G interface which connects the gateway of the WBAN to the internet. The GPS sensor is built in the mobile and used for tracking process. The common used heart beat sensor communicates with the mobile via the Bluetooth LE interface. This heart beat sensor is identified by the Serial number retrieved from its GATT general attributes (see clause A.1.2.3 of the present document.) and is used for the heart beat process. The heart beat sensor has the waist as position (individual of type BodySurface, the subclass of the location class).

While the tracking process has the meter (m) as unit of measurement, the heart beat process has beats per minute (bpm) as unit. The tracking process has two data, the latitude and longitude, and an additional derived data which is the speed calculated based on Haversine formula. The heart beat process has the HR data. Each data has measurements measured by a sensor.

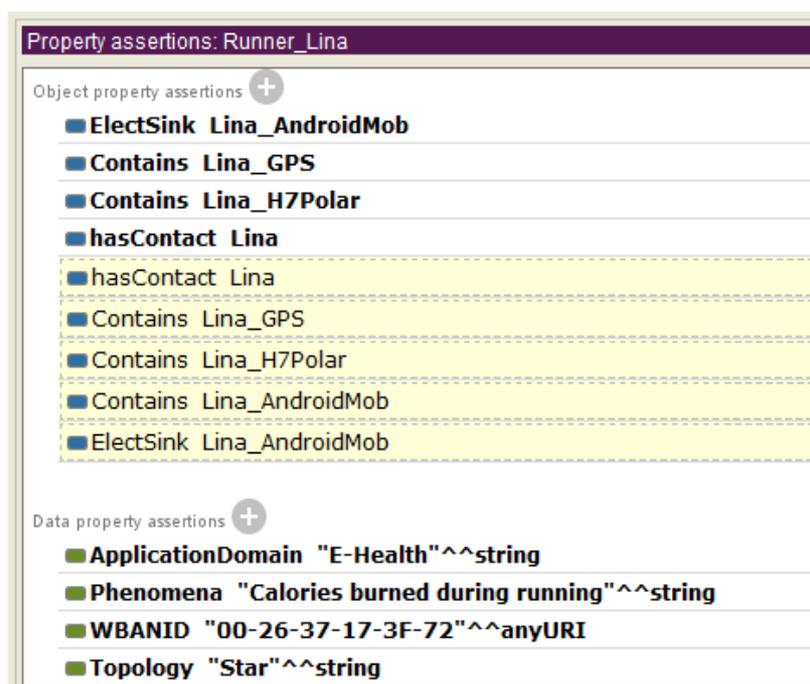


Figure 12: Part of Runner_Lina's WBAN ontology instance

To encourage user to run on higher speed, the maximum heart rate is calculated based on the following formula [i.12]:
 Maximum heart rate= $208 - (0,7 \times \text{Age})$.

Thus, the SWRL rule was added: Patient(?P), MaxHR(?P, ?Q), Age(?P, ?Age), multiply(?x, 0,7, ?Age), subtract(?y, 208, ?x) -> hasValue(?Q, ?y).

If the heart beat sensor measures a value greater than the maximum heart rate, a notification will be sent to the user and the measurement will be considered as invalid in order to stop the running process. To do so, the following SWRL rule is added: WBAN(?W), MaxHR(?P, ?Q), hasContact(?W, ?P), Contains(?W, ?S), measures(?S, ?Mes), usedFor(?S, HeartBeat), value(?Mes, ?measure), hasValue(?Q, ?max), lessThan(?max, ?measure) -> valid(?Mes, false).



Figure 13: GPS Object properties

Figure 13 shows the inferred object properties of Lina_GPS sensor:

- BelongTo Runner_Lina: inferred from the inverse property Contains (Lina_WBAN Contains Lina_GPS).
- Measures: inferred from the inverse property is MeasuredBy (e.g. Lina_Long2 is MeasuredBy Lina_GPS)
- usedFor: inferred from Rule 1 already defined in clause 6.2.4 of the present document.

The maximum heart rate for Lina should be 187. Thus, if the heart beat sensor measures a value greater than this maximum, the measurement should be invalid. Figure 14 shows an invalid measurement.

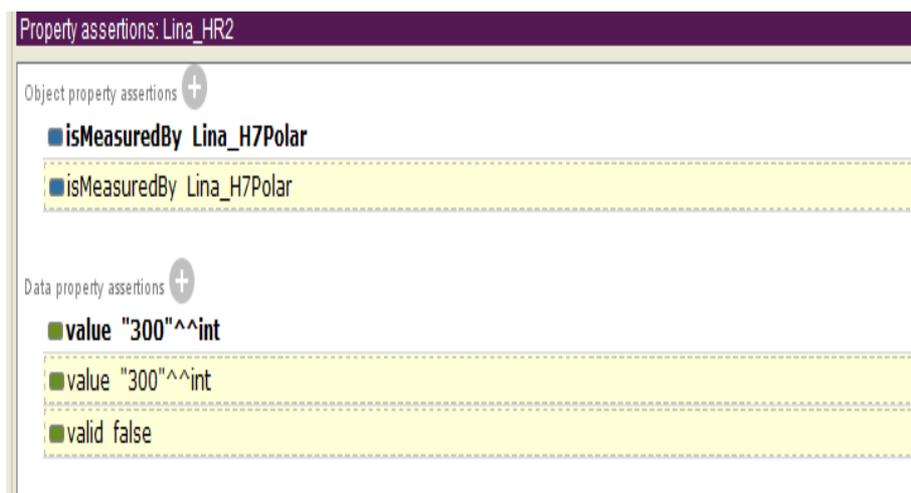


Figure 14: Invalid measurement caused by a value greater than the maximum limit

Using Pellet reasoner, the consistency of the SmartBAN ontology was verified. Pellet reasoner also pointed out that the SmartBAN ontology was well classified. The inferred value was retrieved. More rules and verification can be done to assure the well functionality of the proposed ontology.

To retrieve the information, the SPARQL engine implemented in Protégé has been used. Unfortunately, this engine cannot retrieve inferred data.

Here is the example of the written query for node discovery:

```
SELECT ?WBAN ?Nodes ?Hub
WHERE {
  ?WBAN full:Contains ?Nodes.
  ?WBAN full:ElectHub?Hub.
}
```

The result of the query is given in Figure 15.

WBAN	Nodes	Sink
Runner_Fadi	Fadi_GPS	Fadi_AndroidMob
Runner_Fadi	Fadi_H7Polar	Fadi_AndroidMob
Runner_Lina	Lina_GPS	Lina_AndroidMob
Runner_Lina	Lina_H7Polar	Lina_AndroidMob

Figure 15: Node discovery SPARQL result

Annex A (informative): Background and SoA

A.0 Introduction

This annex presents the SoA, i.e. existing documents, works and architectures that have to be investigated for identifying:

- specifications that should be reused and directly standardized;
- closely related frameworks from which the present document should be inspired; and
- missing parts that have to be fully specified in the present document;

for coming up with the reference specifications of the Smart BANs' open data model. This model is one of the building blocks providing solutions for heterogeneity management in Smart BANs.

A.1 Existing sensor/actuator and BAN data representation

A.1.0 Introduction

In modern medical services and eHealth environments, patients' care information is shared among multiple stakeholders and is also stored in a distributed way for enhancing the management of patient's care. This information, plus data range from patient's medical records, is not only stored in repositories located in patients' care places, but can also be merged with a variety of additional information related to medical research, pharmaceutical products, and information stored within social networks of healthcare interest groups. In that context, a common understanding is needed to mask the heterogeneity of this information. Ontologies represent one technology that can contribute to this goal.

Therefore, the scope of clause A.1 of the present document is to investigate the wireless sensor and the eHealth domains in order to list and evaluate the existing sensor and sensor data representation models in the context of TC SmartBAN. The common used models and corresponding ontologies will be identified, compared and confronted to Smart BAN requirements in order to select the one that have to be adopted or to make known the gaps that have to be addressed by TC Smart BAN Work Item 1.1.

If a SmartBAN dedicated ontology has to be specified and qualified in the present document, common used ontology validation methods will also be presented for that purpose in that SoA/survey in clause A.1.3 of the present document.

A.1.1 Wireless Sensor Networks (WSNs) common used data representation models and ontologies

A.1.1.0 Introduction

In clause A.1.1 of the present document, an overview of existing data representation formats and ontologies of WSN sensors/actuators will be presented. Those ontologies will also be confronted to Smart BAN and eHealth requirements in order to eventually identify the gaps that have to be addressed by TC Smart BAN Work Item 1.1.

A.1.1.1 OGC's Observations & Measurements (O&M) and SensorModel Language (SensorML)

A.1.1.1.1 Observations and Measurements (O&M)

"Observations and Measurements" (O&M [i.13]) model provides XML encoding extensions for the description of sensor observations (i.e. sensor data) and their management. It was proposed by the Open Geospatial Consortium (OGC or OpenGIS) in year 2000 and published as an ISO standard [i.14]. O&M is specified and maintained as a standalone component under the OGC Sensor Web Enablement (SWE) initiative [i.15]. It is presented below.

O&M defines the observation as an act associated with a discrete time period through which a number, term or other symbol, is assigned to a phenomenon. The phenomenon is a *property* of an identifiable object, which is the 'feature of interest' of the observation. The 'feature of interest' is a representation of the observation target, being the real-world object regarding which the observation is made. The observation uses a *procedure*, which is often a device or sensor but may also be a process chain, a human observer, an algorithm, a computation or a simulator. The *procedure* is used to generate the result. The *observedProperty* identifies or describes the phenomenon for which the observation result provides an estimate of its value. Figure A.1 shows the basic observation model defined in O&M.

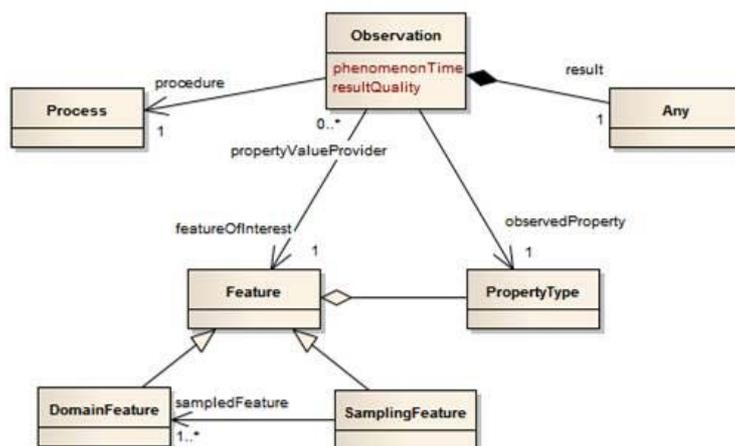


Figure A.1: Basic observation model

An *observation* has a *samplingTime*, which is the time that the result applies to the 'feature-of-interest'. In addition, an *observation* has a *resultTime*, which is the time when the procedure associated with the observation act was applied. An *observation parameter* is a general event-specific parameter that will typically be used to record environmental parameters, or event-specific sampling parameters that are not tightly bound to either the 'feature-of-interest' or the procedure. An *observation* may have both metadata and an indication of the event-specific *resultQuality*. Figure A.2 summarizes the characteristics of an *observation*.

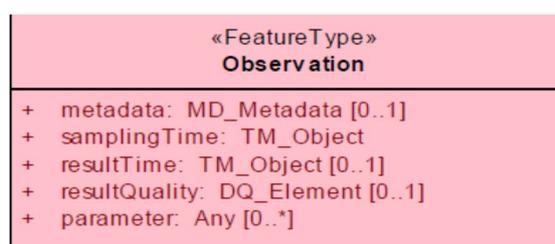


Figure A.2: Observation's properties

An observation could also have different feature's types. Figure A.3 shows the different feature types of an observation and its results.

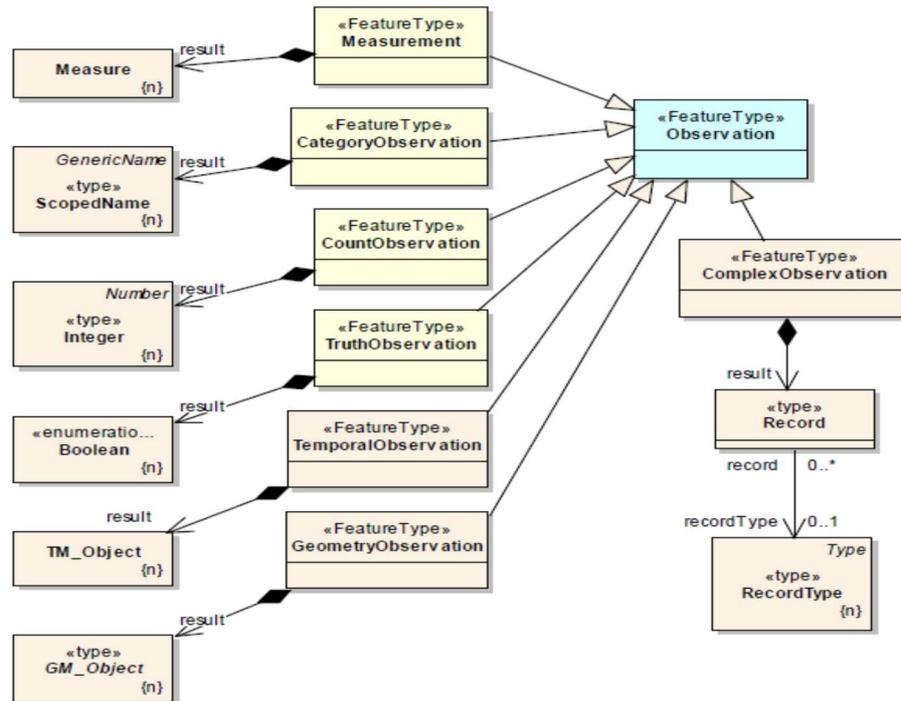


Figure A.3: Specialization of observation by result type

Moreover, there are sensors that are capable of doing these observations and measurements. That is why OGC defined the SensorML language in order to provide all the attributes required for processing, registering, and assessing the quality of measurements from sensor systems. The details of SensorML are provided in clause A.1.1.1.2 of the present document.

A.1.1.1.2 Sensor Model Language (SensorML)

SensorML is an XML model and encoding extensions for sensor and sensor data description/processing that has been proposed by the OGC in 2007 [i.16]. It is specified and maintained as a standalone component under the OGC Sensor Web Enablement (SWE) initiative [i.15]. Even if SensorML was initially dedicated for the earth observation domain, it actually serves as basic language for the formalization of many of the existing sensor ontologies. It is described below.

SensorML was defined for handling two possible roles. The first one is to describe the procedure by which an existing observation was obtained. The second one is to provide processing chains from which SensorML-enabled software could derive on-demand new data from existing observations.

In SensorML, all components are modelled as *processes*. This includes components, normally viewed as hardware (including transducers and actuators) and processors, sensors and platforms. *Processes* take input and generate output through the application of an algorithm defined by a method and parameter values. Figure A.4 shows the conceptual model of SensorML.

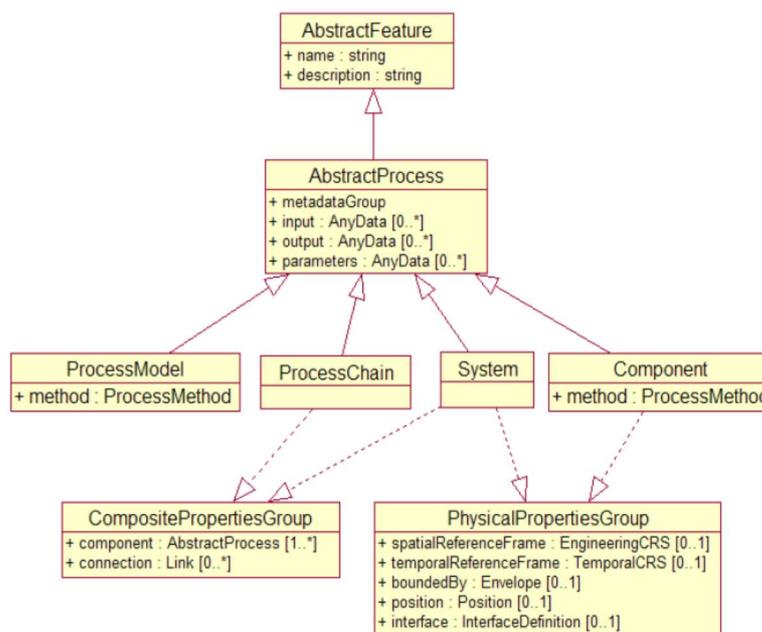


Figure A.4: Conceptual model of SensorML

Within SensorML, all *processes* are derived from an *AbstractProcess* which is itself derived from an *AbstractFeature*. *ProcessModel*, presented in Figure A.4, is used to define more or less atomic pure processes that are expected to be used within more complex process chains. A process chain is defined by:

- the description of all of the *processes* in the chain; and then
- the description of the appropriate connections between components.

In addition to the description of purely mathematical processes, SensorML also describes the physical processes deriving from the abstract *PhysicalProcess*. This abstract *PhysicalProcess* have *spatialReferenceFrame* and *temporalReferenceFrame* properties. Those properties define any spatial or temporal Coordinate Reference Systems (CRS) that might be used for interrelating internal components within the process, as well as any reference frames that might allow this component to be related to other components within a process chain or system. *PhysicalProcess* may also have zero or more interfaces over which commands and data can flow based on particular physical connections and particular protocols. The interface property contains an *InterfaceDefinition* which is based on the Open Systems Interconnection (OSI) reference network layer model, as presented in Figure A.5.

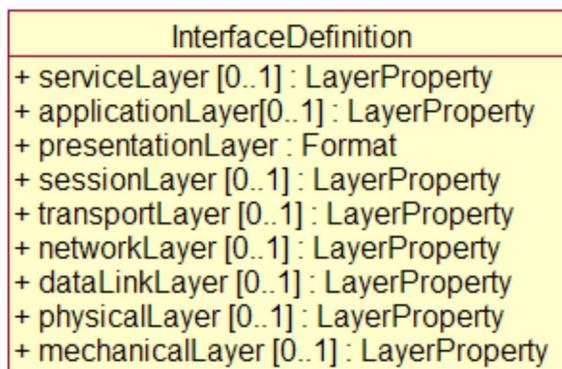


Figure A.5: Interface definition in SensorML

Within SensorML, any physical process can be modelled as a *Component*, if it either cannot be subdivided into smaller sub processes, or if one chooses to treat it as a single indivisible process. A *System* is a physical equivalent of a *ProcessChain*. A *System* may include several physical and non-physical processes that all act for providing a certain set of *System* outputs, based on the *System* inputs and parameters.

A.1.1.2 Existing WSN ontologies

In the last decade, lots of ontologies were proposed for describing WSNs. In [i.17], the authors state a summary of most important ontologies used. They were themselves inspired by [i.18] where a detailed analysis of sensor ontologies has been provided, based on two main topics: 'Sensor' and 'Observation'. This analysis is summarized in the table shown in Figure A.6.

ontology	base concepts	sensor						physical					observation				domain						
		sensor hierarchy	identity & manufacturing	contacting & software	deployment	configuration	history	components	action & process	location	power supply	platform	dimension, weight, etc.	operating conditions	data/observation	accuracy	frequency	response model	field of view/sensing	units of measurement	feature/quality	sampled medium	time
MMI	sensor (system) & process		✓		✓	✓		✓	✓			✓	✓	✓							✓	✓	
CSIRO	sensor & process	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓	✓		
OOSTethys	component, system & process						✓	✓			✓			✓							✓	✓	
CESN	sensor	✓			✓				✓					✓							✓		✓
SWAMO	agent, process & sensor			✓			✓	✓	✓		✓			✓				✓		✓	✓		✓
Kim	sensor					✓			✓					✓	✓	✓		✓			✓		
OntoSensor	component & sensor	✓			✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓		✓
Eid	sensor		✓		✓				✓	✓				✓	✓	✓	✓	✓					
Matheus	system & sensor	✓		✓				✓	✓					✓		✓							
Avancha	sensor			✓					✓	✓				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ISTAR																							

Figure A.6: Comparison of the existing ontologies based on Sensor & Observation

Figure A.6 shows that CSIRO ontology is the ontology which fully describes the sensor and its physical features. However it does not describe the data transferred between sensors.

Figure A.7 summarizes the comparison done in [i.17] where the authors have added 'data' as a third topic for comparing the existing WSN ontologies.

Ontologies	Sensor	Observation	Data										
			Data	Data Stream	Sensing Process	Communicating Process	Transforming Process	States	Data Quality	Acquisition Policy	Communication Policy		
	8 facets	5 facets											
SSN Ontology	8/8	4/5	*		*							*	
CESN Ontology	2/8	1/4	*		*								
CSIRO Ontology	8/8	4/5	*		*							*	
Sensei O&M Ontology	Not available	Not available	*		*								
OOSTethys ontology	2/8	2/5	*		*								
MMI Ontology	5/8	Not available			*							*	
SWAMO Ontology	3/8	2/5			*								
SEEK Ontology	Not available	Not available	*		*								
SDO Ontology	2/8	2/5	*		*							*	
SeRes O&M Ontology	Not Available	Not available	*		*								
OntoSensor Ontology	5/8	5/5	*		*							*	

Figure A.7: Comparison between existing ontology based on Sensor, Observation & Data

A detailed analysis of the comparisons, presented in Figure A.7, shows that SSN ontology seems to be the best ontology for describing sensors, contrary to OntoSensor Ontology that seems to be best one for describing observations and data. Clause A.1.1.3 and clause A.1.1.4 of the present document will detail those two common used ontologies.

A.1.1.3 OntoSensor ontology

OntoSensor is stemming from a combination of SensorML defined by OGC, IEEE Suggested Upper Merged Ontology (SUMO) and the International Organization for Standardization [i.20]. Its latest update was released in 2008. The main objective of OntoSensor is to provide an ontological description for data observation of sensors. Figure A.8 shows the different parts of OntoSensor Ontology.

OntoSensor ontology [i.19] supports data discovery, processing and analysis of sensor measurements, geo-location of observed values (measured data), performance characteristics (e.g. accuracy, threshold, etc.), explicit description of the process by which an observation was obtained (i.e. its lineage). It also provides an executable process chain for deriving new data products on demand.

Although OntoSensor illustrates a semantic approach to sensor description and provides an extensive knowledge model, there is no distinctive data description model to facilitate interoperable data representation for sensors observation and data. This is however quite mandatory for Smart BANs.

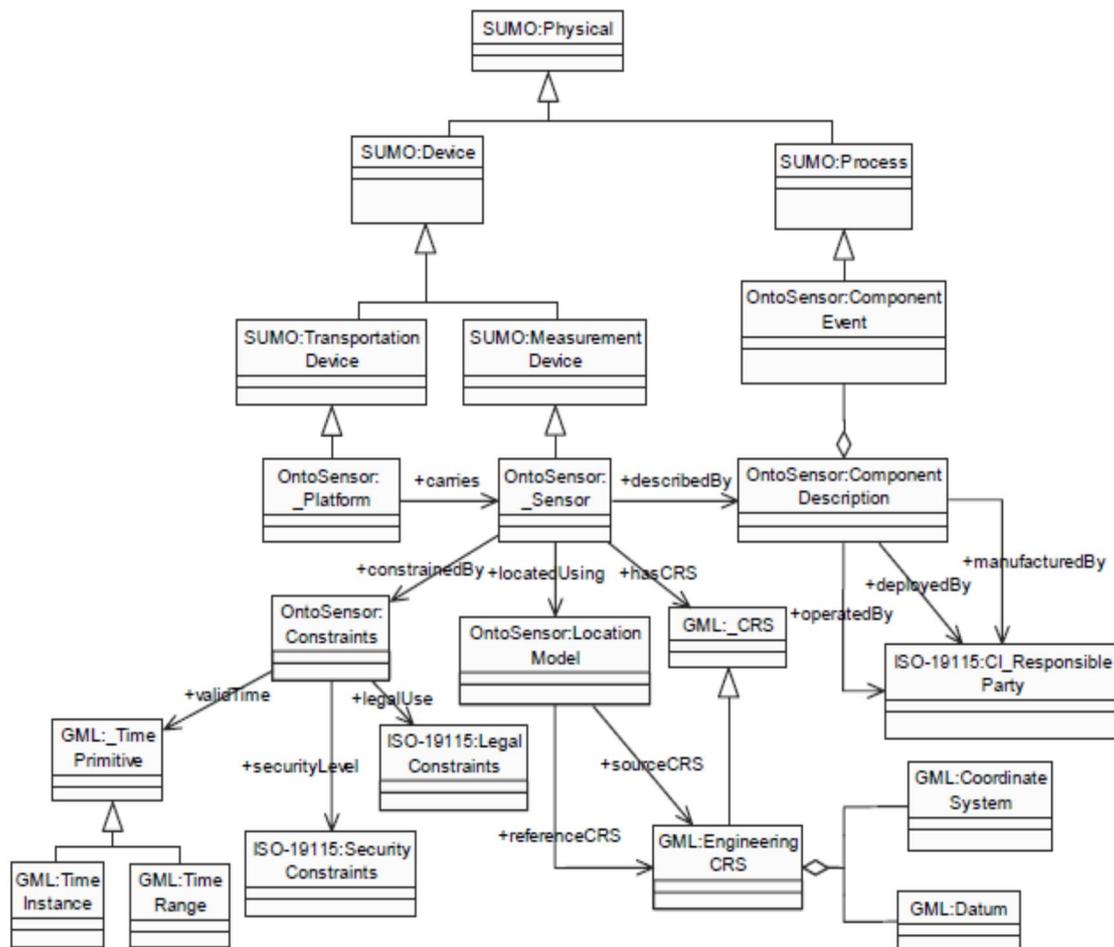


Figure A.8: OntoSensor ontology

A.1.1.4 Semantic Sensor Network ontology (SSN)

The most important ontology that includes sensor, observation and data description is Semantic Sensor Network ontology (SSN) [i.21]. Developed by W3C Semantic Sensor Network Incubator Group, this ontology describes the capabilities of sensors, the measurement processes used and the resultant observations. SSN can also be aligned with other ontologies that describe e.g. observed phenomena. This ontology covers large parts of the SensorML and O&M standards from the OGC, omitting calibrations as well as process descriptions and data types, which were deemed not sensor specific (if required it can always be included from other ontologies). However, SSN does not provide facilities for abstraction, categorization, and reasoning offered by semantic technologies.

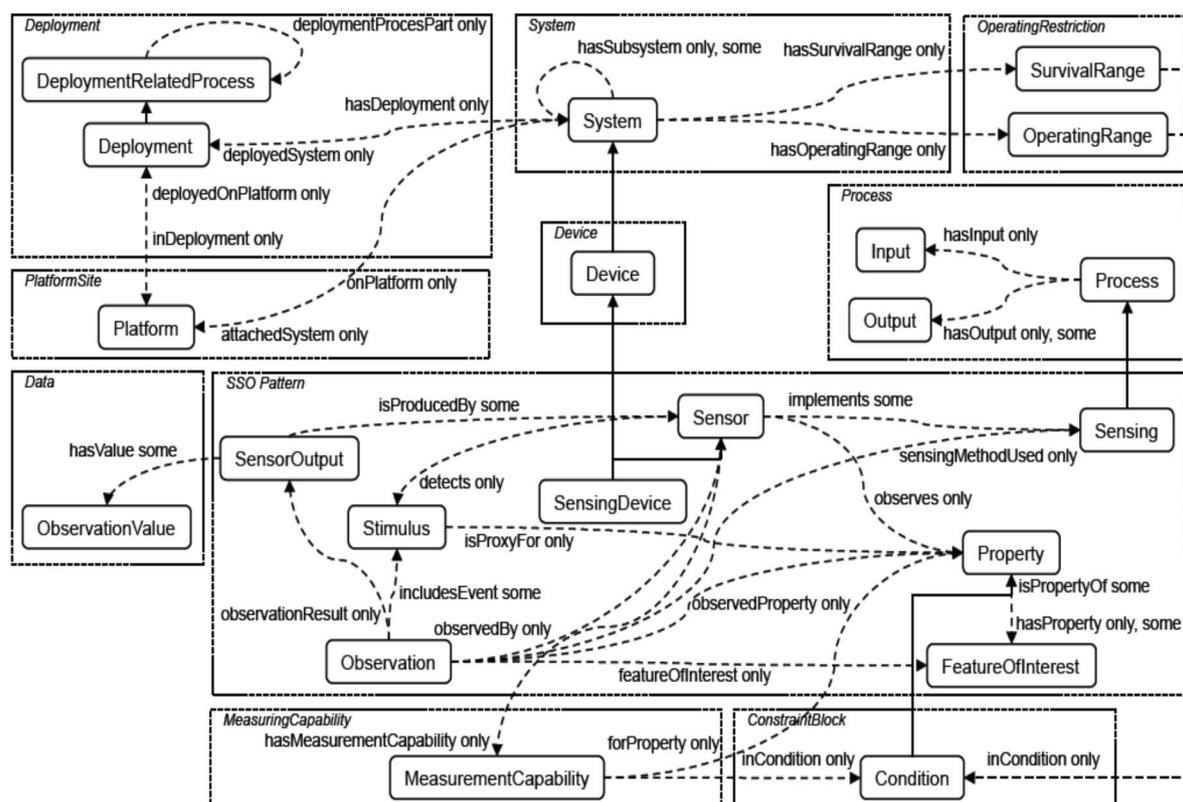


Figure A.9: SSN ontology

Figure A.9 shows that SSN is focusing on the deployment of the wireless sensor network, the description of the sensors and the phenomena it is measuring. The ontology can be used for a focus on any (or a combination) of a number of perspectives:

- A sensor perspective, with a focus on what is sensed, and how it is sensed.
- A data or observation perspective, with a focus on observations and related metadata.
- A system perspective, with a focus on systems of sensors.
- Or a feature and property perspective, with a focus on features, their properties, and what can sense those properties.

However, SSN ontology does not focus on the communication process. In order to overcome this limitation, W3C members introduced, in the eleventh International Semantic Web Conference, an extension of SSN ontology called Wireless Semantic Sensor Network ontology (WSSN). This extension is presented in clause A.1.1.5 of the present document.

A.1.1.5 WSSN ontology

WSSN was proposed by W3C to extend SSN with three new concepts: the communication process, the data stream and the state. The "Communicating class" is added to the ontology for describing the sensor communication process. In addition to that, a "Communication Output class" is added for describing data transmitted by the sensor (the communicating device). The resulting data stream, if a communication occurs, is defined as a set of communications while the acquisition data stream is defined as a set of observations. A communicated data can be equal to a data acquired by sensor or to a data generated from a set of data acquired by sensors using, for example, some aggregation procedure.

The WSN node and the observed phenomenon pass through several states. In the WSSN ontology [i.17], the state of any entity is represented by the "State class".

A.1.1.6 Semantic Web Based Architecture for Managing Hardware Heterogeneity

A new semantic ontology was proposed in 2011 in [i.22] by Nikolić, Penca, Segedinac and Konjović for managing hardware heterogeneity in wireless sensor network. The proposed architecture, "Semantic Web Based Architecture for Managing Hardware Heterogeneity", consists of three segments: Application, Middleware and WSN.

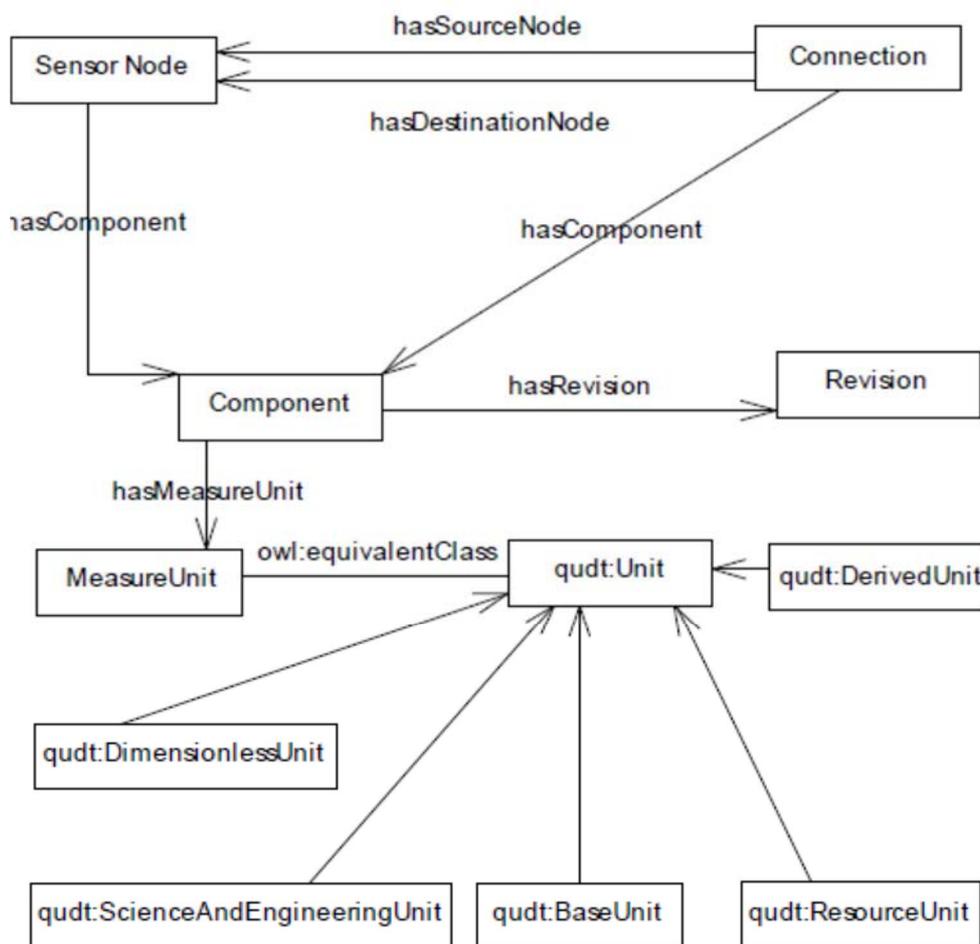


Figure A.10: WSN in Semantic Web Based Architecture

Figure A.10 shows that this ontology describes the sensor, its physical features (dimension, platform.), the connection and the data measured. It uses the same features described in SensorML to describe a node property, a component and the data. In addition, it includes the following additional features:

- Data & Data Stream. The ontology uses DateTime and Value fields in the "ReadingSensorstotable" to describe the data stream.
- Communication Process & Policy. The ontology includes Radio component that describes the RadioType and RadioFrequency.
- Acquisition Policy. This field indicates the interval of data acquisition.
- Data Quality. However, this field is not covered by the ontology.

Moreover, "Semantic Web Based Architecture for Managing Hardware Heterogeneity" ontology includes a Processing Component composed of Memory Component, not mentioned in the ontologies cited previously. Figure A.11 shows the Component structure in this ontology.

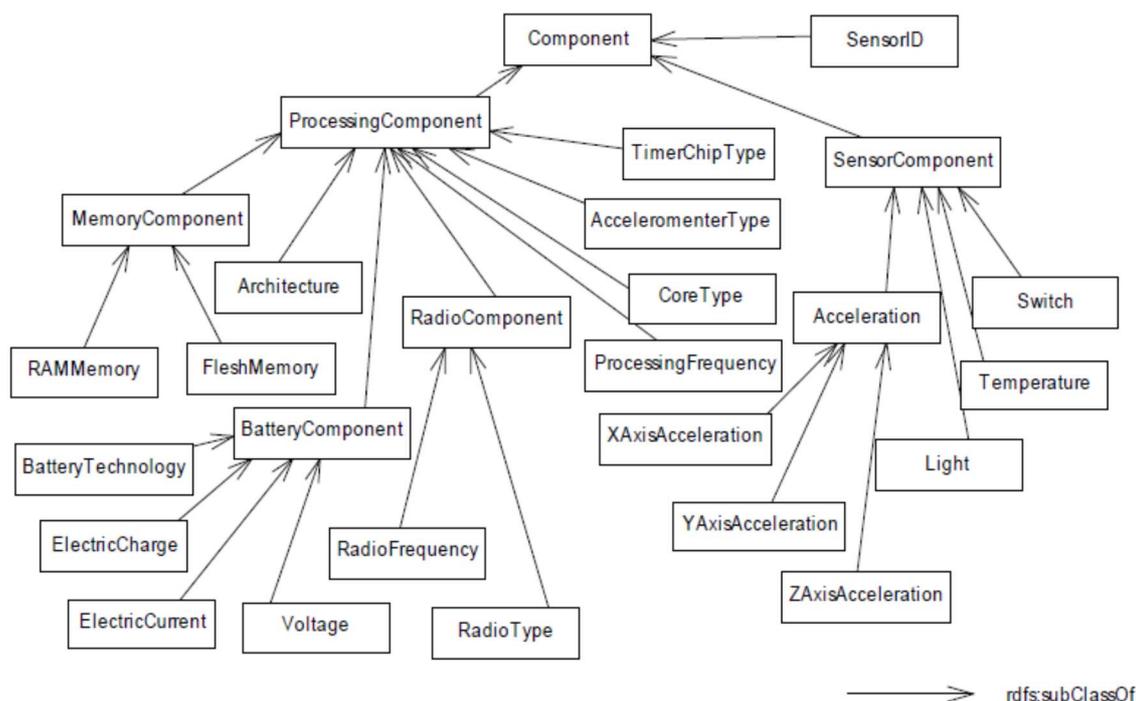


Figure A.11: Component Structure in Semantic Web Based Architecture

The Processing component presented in Figure A.11 may be very useful for the management of the Wireless sensor Network.

A.1.2 Proposed sensor ontologies in the eHealth sector

A.1.2.1 CEN TC 251 Health Informatics

CEN/TC251 [i.23] has been founded in 1990. Its objective is the standardization in the field of health Information and Communications Technology (ICT) to achieve compatibility and interoperability between independent systems and to enable modularity.

CEN/TC251 has developed EN 13606 [i.24] for Electronic health record communication which follows a dual model methodology. The CEN/TC251 EN 13606 norm is composed of five parts that are summarized below.

Part 1: Reference Model

The Reference Model formalizes the global characteristics of health record components, i.e. how they are aggregated, and the context information required to meet ethical, legal and provenance requirements. Figure A.12 describes the reference Model.

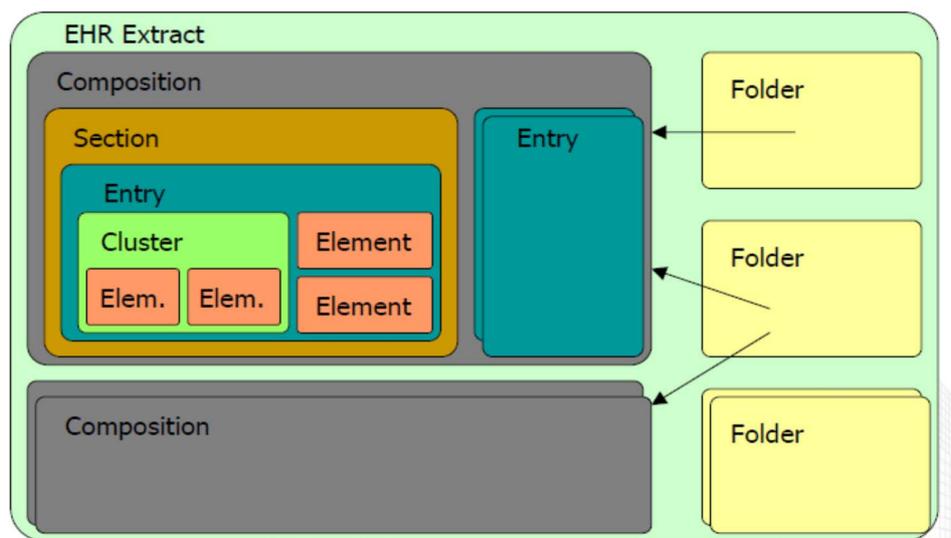


Figure A.12: CEN TC 251 reference model

Entry, Composition (which is the set of information committed to one Electronic Health Record- EHR - result) and elements of each EHR describe the clinical data related to the patient, the diseases and the collected data. The cluster allows the specification of nested multi-part data structures such as time series, list or tables.

Each element has one Data_Value. The Data_Value of the reference model describes all the types of data that can be found in the biomedical environment. Figure A.13 summarizes the Data_Value types.

Basic data types		Codes and texts	
INT	II	CS	CD
REAL	URI	CV	SIMPLE_TEXT
BL	ED	CE	CODED_TEXT
OID	IVL<T>		

Quantities		Date and time	
PQ		DATE	PIVL
QUANTITY_RANGE		TS	EIVL
RTO		DURATION	
ORD			

Figure A.13: Data_Value in Reference Model

Part 2: Archetype Model

An archetype is expressed in the form of constraints on the Reference Model. These constraints can consist in defining relevant attribute values, optionality and multiplicity of attributes and objects, data types and value ranges that data instances may take, and finally binding to clinical terminologies or ontologies. The archetype model will group the data collected from the ontology to respect the adequate format and repartition.

Part 3: Reference archetypes and term lists

The term lists contain a list of biomedical terms. They can be used as data dictionary for the service layer.

Part 4: Security

Health records have to be created, processed and managed in ways that: guarantee the confidentiality of their contents and legitimate control by a patient in their usage.

Part 5: Interface specification

The interface specification defines the computational view point of each interface as the payload to be communicated.

A.1.2.2 IEEE reference models for medical device communications

ISO/IEEE 11073 [i.25] Personal Health Device (PHD) standards are a group of standards addressing the interoperability of personal health devices (PHDs) such as weighing scales, blood pressure monitors, blood glucose monitors, ... The standards draw upon earlier ISO/IEEE 11073 [i.25] standard works, but differ from those earlier works due to an emphasis on devices for personal use (rather than hospital use) and the use of a simplified communication model. The central core of the standard is the so-called Domain Information Model. Objects containing vital-sign data representations and their relationships are defined in this model. Objects for additional services around vital signs data objects, are also defined. The ISO/IEEE 11073 [i.25] model is summarized in Figure A.14.

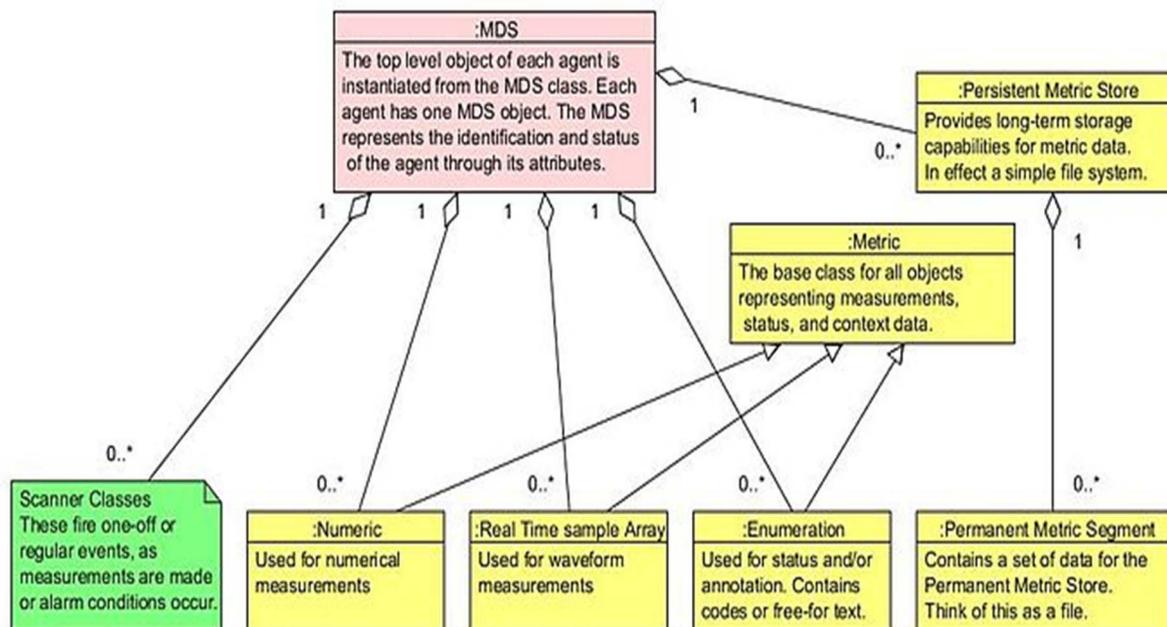


Figure A.14: ISO/IEEE 11073 [i.25] model summary

Numeric objects relate to the physiological parameters and have as attributes the mechanism to obtain an observed value and its status such as units and the timestamp. The Real Time and Enumeration attributes are used to represent a group of data. The Scanner Class determines the way the data is transmitted from sender to destination. It provides mechanisms to reduce message overhead by communicating the message format at configuration time and then sending pure data during runtime. The Storage Class, called PM-Store, provides a facility to store data for longer periods of time and also provides mechanisms to transfer portions of data that are needed by the receiver. Within the ISO/IEEE 11073 [i.25] standard, device specialization sub-standards have been described.

A.1.2.3 Bluetooth LE (Low Energy) profiles for medical devices proposed by Continua Alliance

Bluetooth LE (Low Energy) [i.26] was proposed and specified by the Bluetooth SIG for providing the current standard with lower energy working process, thus allowing its usage in button cells and energy harvesting applications (like e.g. eHealth or Internet of Things applications). For that purpose, Bluetooth SIG members fully redesigned the physical and MAC layer of Bluetooth, as well as its protocol stack. At the upper layer level, they introduced a simplified device and application profile called GATT (Generic Attribute Profile), provided with the corresponding discovery and access protocol called Attribute Protocol. All the profiles that will be introduced within Bluetooth LE will be derived from the generic GATT one.

Within GATT, all the data are exposed as attributes. An attribute has:

- A unique identifier called UUID.

- A type.
- A value, with fix or variable length (from 0 to 512 octets).
- And a permission. The permission is used for setting the attribute's access rights for reading and or writing.

A device is characterize by the following attributes:

- Manufacturer Name, a String representing the name of the manufacturer of the device.
- Model Number, a String representing the model number that is assigned by the device vendor.
- Serial Number, a String representing the serial number of a particular instance of the device.
- Hardware Revision, a String representing the hardware revision for the hardware within the device.
- Firmware Revision, a String representing the firmware revision for the firmware within the device.
- Software Revision, a String representing the software revision for the software within the device.
- System ID, a structure containing an Organizationally Unique Identifier (OUI) followed by a manufacturer-defined identifier. This ID is unique for each individual instance of the product.
- Regulatory Certification Data List, representing regulatory and certification information for the product in a list defined within ISO/IEEE 11073-20601 [i.25].

Within the GATT specification, units are given using the international standards for the measurement of physical quantities, such as e.g. meter for length or kilogram for mass. The type of the units is determined in the 'Format Types' attribute.

The "Attribute Protocol" is a client/server based protocol providing attribute exchange functionalities between devices. GATT and "Application Protocol" upper layer modules are also associated with "Generic Access Profile" (GAP) and "Access Manager" modules that provide secure device discovery, access and connection functionalities. The corresponding device discovery, access and connection profiles are specified within the GAP module.

Based on that new Bluetooth LE standard, the Continua Alliance [i.27] specified new device/service profiles dedicated to medical devices and eHealth applications. It defines 13 different profiles that determine how services can be used to enable an application or use case. Some of these profiles are dedicated for notification, while some others are dedicated for measurement and for client server communication. These profiles are detailed below.

The HID Over GATT Profile (HOGP) defines the way a Bluetooth LE device can support Human Interface Device (HID; e.g. Heart Rate Monitor, Glucose Meter, Changed Oximeter, Mobile Phone) services using the Generic Attribute Profile.

The 'Measurement Profiles' are used to determine how a Connector could connect and interact with the sensor for being used in health care applications. It includes blood pressure, cycling power, cycling speed and cadence, glucose, temperature, heart rate, location and navigation, proximity, running speed and cadence.

The Time profile is used to get the date and time attributes.

The Alert Notification Profile (ANP) enables a client device to receive different types of alerts and event information. For example, the Phone Alert Status profile is used for obtaining the phone alert status exposed by a phone.

The Scan Parameters Profile (SPP) is used for providing devices with information assisting them in the management of their connection idle timeout and advertising parameters in order to optimize their power consumption and/or reconnection latency.

A.1.2.4 ASTM E31

E31 [i.28] Committee on Healthcare Informatics of American Standards for Testing and Materials (ASTM) develops standards related to architecture, content, storage, security, confidentiality, functionality, communication of healthcare information and decision making (including patient-specific information and knowledge). ASTM E31 has also developed some standards for defining health vocabularies, Electronic Health Record (EHR) system management (including interactions between different parties), as well as for ensuring security and privacy of Healthcare systems.

Four messaging standards were created:

- ASTM E1238-97 standard specification [i.29] for transferring clinical observations between independent computer systems (Withdrawn 2002).
- ASTM 1394 standard specification [i.30] for coded values used within the EHR. This standard allows the representation of different biomedical signals, with the cooperation of Health Industry Level 7 (HL7), for supporting multichannel signals (Withdrawn 2002).
- ASTM E1467-94(2000) standard specification [i.31] for transferring digital neurophysiological data between independent computer systems (Withdrawn 2004). It defines the message structure exchanged between clinical instruments (Withdrawn 2004).
- E2369 standard specification [i.32] for the Continuity of Care Record (CCR). This recent specification gives a particular and detailed description of data (and its organization into structured textual forms) that are dedicated for the communication between healthcare enterprises and that may not be interoperable otherwise. This specification details the abstraction of data contained in the EHR attributes. These data are documented in practice E-1384 [i.33] and are organized and composed into a textual view for their transfer to other care settings that may not utilize a structured electronic representation of patient data. The textual form is used in order to provide a familiar cognitive format for information exchange between practitioners that are currently operating using traditional unstructured care settings.

A.1.3 Ontology validation methods

A.1.3.0 Introduction

In clause A.1.3.0 of the present document, an overview of existing ontology validation methods is presented. Those models will be investigated here with the objective of selecting the most appropriate one for qualifying the Smart BAN retained and proposed unified ontology.

For qualifying and validating an ontology, three approaches have already been defined:

- Evolution-based validation.
- Symbolic-based validation.
- Attribute-based validation.

The first aforementioned validation method consists in observing the evolution of the ontology usage, over the time. The original ontology schema is a posteriori compared to all the instances of that ontology that was introduced and used during a given period of time. The retained evaluation criteria are, for example:

- Ontology domain changes. It is introduced for tracking any new knowledge that could have been added to the domain formalized by the ontology.
- Changes in the ontology usage perspectives in a given domain. It is introduced for tracking any changes in ontology usage impacting the ontology conceptualization.
- Ontology specification changes. It is introduced for tracking ontology stability by detection of the number of new objects or attributes that have been introduced in the original ontology graph.

In the context of Smart BANs, it is clear that this validation method cannot be used alone since it is mandatory to validate the specified ontology before its usage in eHealth/medical applications. This validation method has therefore to be combined with either a symbolic based and/or an attribute based approach.

The second validation approach is the symbolic one. It is a rule-based evaluation where two rule sets are defined: one containing rules directly coming from the ontology itself and the other containing rules coming from the user domain. The first set encompasses rules like dissimilarities, matching, inclusion or inheritance between objects and or attributes. The second set incorporates rules coming from the user domain for identifying conflicting properties in the ontology specifications.

Finally, the third approach consists in scanning the ontology graph for measuring the knowledge level through the use of quantitative metrics like, e.g. location and distribution of the ontology objects in the graph.

All the emerging ontology frameworks for each of the aforementioned approaches will be identified, introduced and evaluated in the scope of TC SmartBAN.

A.1.3.1 Common used symbolic-based method

While ontologies are used to infer implicit knowledge, the evaluation approach based on rules is essential. Basically, this approach checks for consistency which means that the ontology does not contain any contradictory facts. From literature [i.34] three consistency's types can be distinguished:

- **Structural consistency:** to check that the ontology respects the rules underlying the ontology language. In OWL language, it means checking for TBox rules. It means to verify the classes' structures like subclasses, disjoint classes and equivalent classes. For example, a subclass of a class should be a class.
- **Logical consistency:** to validate that the ontology conforms the logical theory of the ontology. These rules are describes in Abox rules. They allow the verification of the data properties and object properties constraints. The domain and ranges are checked in addition to the values, the equality between properties and the inequality between properties. Moreover, the logical consistency assures that a functional property should be unique in the ontology model. The inverse properties, reflexive, irreflexive, symmetric and asymmetric properties are tested in this level.
- **User-defined:** These rules are added by the users. Some inferences can be gathered from the ontology model itself, but others may not be expressible in the ontology language (usually OWL) and require a more functional representation. Here comes the role of the Semantic Web Rule Language SWRL [i.11].
- As part of the owl rules, the user can determine the maximum cardinality and minimum cardinality for the object properties.

After consistency checking, the satisfiability (i.e. if it is possible for a class to have instances) is tested. Then, the classification process is executed in order to create the complete class hierarchy. Finally, the realization is executed where most specific classes that individuals belongs to are shown.

A.1.3.2 Common used attribute-based methods

A wide variety of metrics has been proposed in order to evaluate the ontologies in terms of complexity and completeness and other metrics were proposed in order to compare between different ontologies and rank it.

OntoClean [i.35] is a framework that helps developers to evaluate their ontologies in order to check for inconsistency and conflicts. The developer should add meta-property (Essence, Rigidity, Identity & Unit) for the predefined properties. A property is tagged as "Essence" if it is essential to it. A special form of essentiality is rigidity. In this case, the property is essential for all entities. Thus, a property can vary from being rigid, semi-rigid to anti-rigid (i.e. which means not essential to all properties). The other type of meta-property is used to determine the equality between the entities. This is done by indicating the identity of the property. In addition, the developer can designate the unity of a property (if it is a unit property or depends of other properties). The unity will help in checking the consistency of the ontology. Ontoclean can be used with Protégé. However, OntoClean is considered complex for a developer especially if he is dealing with large ontologies where he has to add meta-property for many properties.

The OntoQA tool developed by LSDIS Lab at the University of Georgia is a simpler analysis method that includes a number of metrics that includes individuals, thus it allows for the automatic measurement of ontologies. In OntoQA [i.34], metrics (features) are divided into two groups: schema metrics, which address the design of the ontology schema, and instance metrics, that address the way instances are organized within the ontology. Although the ontology design accuracy of modelling the domain knowledge cannot be definitely known, metrics in this category indicate the richness, width, depth, and inheritance of an ontology schema design. This is done by calculating:

- **The relationship richness.** It measures the number of the properties in the selected class that are actually being used in the instance ontology relative to the number of relationships defined for the selected class in the ontology definition.
- **Inheritance richness.** It shows the number of inheritance relationship from the total number of relations.
- **And attribute richness.** It indicates the distribution of instance over classes.

The way data is placed within ontology is also a very important measure of ontology quality because it can indicate the effectiveness of the ontology design and the amount of real-world knowledge represented by the ontology. Instance metrics include metrics that describe the KB (Knowledge Base) as a whole, and metrics that describe the way each schema class is being utilized in the KB. These metrics are the class richness, class connectivity that indicates the number of instances of other classes connected by relationships to instances of the selected class, class importance and the cohesion.

Contrary to the previous methods that are used only by developer, OntoCAT ontology consumer analysis [i.36] is proposed to be used by ontology developer and user for evaluation purposes. It is composed of two metrics categories: intentional metrics and extensional metrics. Intentional metrics are calculated based on the ontology definition itself, i.e. its classes and subclasses and their properties. Extensional metrics deal with the instances and how effectively the ontology is including the domain knowledge. In other terms, OntoQA schema metrics match OntoCAT intentional metrics, and OntoQA instance metrics match OntoCAT extensional metrics calculated on the ontology occurrences [i.36]. OntoCAT define the following groups of metrics:

- Intentional size metrics: show the numbers of classes, relationships and properties in a tree or sub-tree.
- Extensional size metrics: show the number of occurrences of classes, relationships and properties.
- Intentional structural metrics: show structural metrics are similar to size metrics, since they are over the entire intentional ontology, i.e. over all the root trees defined in the ontology (if no concept or class is specified).
- Extensional structural metrics: same as the previous metrics but on occurrences.
- Summarization metrics: select the object occurrences (for extensional) and classes (for intentional) having the maximum number of links in handout. For intentional, the count of links is the number of subclasses and superclasses defined. For extensional, the links are based on the relationships specified for creating its structure.

OntoCAT can be used during the life cycle of the ontology due to the use of extensional metrics that shows the evaluation of the ontology after individuals' creation.

OntoMetric [i.37] is designed to help the users in choosing the appropriate ontology. It checks the content, the language, the developed methodology, the building tools and the usage cost to decide which ontology is suitable for a certain domain of application. The user should choose a reference ontology, and based on the analytic hierarchy process, it decides weather or not to reuse the ontology.

In conclusion, where some evaluation methods were designed to help the users in selecting the adequate ontology, others focus on helping the developers to identify the complexity of their ontologies, the core of their ontologies and the consistency. In fact, while the users look for accuracy, adaptability and extensibility, clarity, and organizational fitness in certain domain, the developers should provide conciseness (no irrelevant elements or redundant representation of semantics), lightness (minimum allocation resources in terms of memory and processing), consistency (no contradictions) and flexibility to be applied in different applications. Thus, the ontology should be tested during the development life cycle, evaluated by users during its usage and ranked comparing to other ontologies covering the same domain. A combination of the previous mentioned methodologies and maybe new methodologies can be used to evaluate an ontology.

A.1.4 Preliminary conclusion concerning existing sensor ontologies

Lots of ontologies were proposed to manage WSN heterogeneity focusing on different application domains or operation management. OGC proposed different standards to describe the sensor nodes, the data and the observation process (SensorML and O&M Observation). However, the description is not based on semantic ontology and is therefore not allowing similarity detection or conflict resolution that have in particular to be handled within SmartBANs. W3C incubator has proposed the SSN ontology which describes the sensor nodes, data and observation process. WSSN has next extended SSN by adding the communication process, the data streaming and the state to the ontology specifications. Faculty of Technical Sciences, University of Novi Sad focused on solving the hardware heterogeneity in wireless sensor network. It proposed an ontology that describes the component, the sensor nodes, the data, the communication process and Energy component of the sensor. However, to effectively manage a wireless sensor network, more components should be added for aggregation function, data fusion, routing, error detection and others.

On the eHealth side, lots of standards for healthcare message exchange and terminology have been developed such as CEN TC251 [i.23], ISO/IEEE 11073 [i.25], ASTM E31 [i.28] or Bluetooth profiles for medical devices. CEN TC 251 (EN 13606 [i.24] standard) defines the high-level logical models for any kind of EHR and hereby enables syntactic interoperability. However, this only guaranties common data structure exchange procedures but does not ensure that the data meaning will be interpreted identically by all parties. Regarding ISO/IEEE 11073 [i.25], it defines the data format, in addition to the data storage and data transmission, for eHealth environments. ASTM E31 short analysis shows that this standard is the closest to an EHR object model. However, it is not so extensible and still lacks a lot of essential information. Finally, Bluetooth LE alleviates the interoperability between medical devices by presenting specific data formats and units, in addition to the notification systems and communication between different medical parties. Unfortunately it is only dedicated for Bluetooth enabled devices.

In conclusion, none of the existing ontologies, as well as no combination of the existing ontologies, is able to provide a complete level of reasoning over medical data stored in multiple locations. That's confirms the need of a specification and qualification of a unified extended data representation model and transfer format in order to enhance the management of EHR systems and make Smart BANs a reality. This SmartBAN open data model is specified in clause 6 of the present document.

Annex B (normative): OWL-DL formalization of the SmartBAN ontology

B.1 Wban.owl

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<!-- http://www.engenoid.com/onto/TCSmartBAN/wban#Patient -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/wban#Patient">
<rdfs:subClassOf rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/wban#Person"/>
</Class>
<!-- http://www.engenoid.com/onto/TCSmartBAN/wban#Periodic -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/wban#Periodic">
<rdfs:subClassOf rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/wban#CommunicationProcess"/>
</Class>
<!-- http://www.engenoid.com/onto/TCSmartBAN/wban#Person -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/wban#Person">
<rdfs:subClassOf rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/wban#Contact"/>
</Class>
<!-- http://www.engenoid.com/onto/TCSmartBAN/wban#ResponsibleParty -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/wban#ResponsibleParty">
<equivalentClass>
<Class>
<unionOf rdf:parseType="Collection">
<rdf:Description rdf:about="http://www.engenoid.com/onto/TCSmartBAN/wban#Organization"/>
<rdf:Description rdf:about="http://www.engenoid.com/onto/TCSmartBAN/wban#Person"/>
</unionOf>
</Class>
</equivalentClass>
<rdfs:subClassOf rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/wban#Contact"/>
</Class>
<!-- http://www.engenoid.com/onto/TCSmartBAN/wban#WBAN -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/wban#WBAN"/>
</rdf:RDF>

```

B.2 Nodes.owl

```

<rdf:RDF xmlns="http://www.w3.org/2002/07/owl#"
  xml:base="http://www.w3.org/2002/07/owl"
  xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
  xmlns:owl="http://www.w3.org/2002/07/owl#"
  xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
  xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#">
<Ontology rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes"/>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#DutyCycle -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#DutyCycle">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Processor"/>
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#MIPS -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#MIPS">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Processor"/>
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#ModePower -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#ModePower">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Modes"/>
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#NodeDiscoveryTime -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#NodeDiscoveryTime">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#NodeType"/>
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#Position -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#Position">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Node"/>
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#WakeupLatency -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#WakeupLatency">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#NodeType"/>
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#cost -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#cost">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#NodeType"/>
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#dimension -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#dimension">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#NodeType"/>
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#frequency -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#frequency">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Processor"/>

```

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</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#hasAvailableFlash -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#hasAvailableFlash">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#MemoEnergy" />
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#hasAvailableRAM -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#hasAvailableRAM">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#MemoEnergy" />
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#hasEnergySrc -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#hasEnergySrc">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#EnergySource" />
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#NodeType" />
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#hasInterface -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#hasInterface">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Interface" />
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Node" />
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#hasInterfaceType -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#hasInterfaceType">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#InterfaceType" />
<rdfs:domain>
<Class>
<unionOf rdf:parseType="Collection">
<rdf:Description rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#Interface" />
<rdf:Description rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#NodeType" />
</unionOf>
</Class>
</rdfs:domain>
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#hasLinkState -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#hasLinkState">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#LinkState" />
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Node" />
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#hasLinkToNode -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#hasLinkToNode">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#LinkState" />
<rdfs:range rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Node" />
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#hasMAXFlash -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#hasMAXFlash">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Processor" />
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#hasMAXRAM -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#hasMAXRAM">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Processor" />
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#hasMemoEnergy -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#hasMemoEnergy">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#MemoEnergy" />
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Node" />
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#hasModes -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#hasModes">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Modes" />
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#NodeType" />
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#hasNodeType -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#hasNodeType">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Node" />
<rdfs:range rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#NodeType" />
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#hasProcessor -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#hasProcessor">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#NodeType" />
<rdfs:range rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Processor" />
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#hasRemainBattery -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#hasRemainBattery">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#MemoEnergy" />
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#inCoverage -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#inCoverage">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#NodeType" />
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#inCurrentMode -->

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<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#inCurrentMode">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Modes"/>
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Node"/>
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#outCoverage -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#outCoverage">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#NodeType"/>
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#receivingSensitivity -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#receivingSensitivity">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#NodeType"/>
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#velocity -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#velocity">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#NodeType"/>
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#Add_Type -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#Add_Type">
<rdfs:subPropertyOf rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#InterfaceAddress"/>
<rdfs:range rdf:resource="&xsd:string"/>
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#Add_value -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#Add_value">
<rdfs:subPropertyOf rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#InterfaceAddress"/>
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#ErrorRate -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#ErrorRate">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#LinkState"/>
<rdfs:range rdf:resource="&owl:real"/>
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#Firmversion -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#Firmversion">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#NodeType"/>
<rdfs:range rdf:resource="&xsd:string"/>
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#Firmware -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#Firmware">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#NodeType"/>
<rdfs:range rdf:resource="&xsd:string"/>
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#IntDescription -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#IntDescription">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#InterfaceType"/>
<rdfs:range rdf:resource="&xsd:string"/>
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#IntLayer -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#IntLayer">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#InterfaceType"/>
<rdfs:range rdf:resource="&xsd:string"/>
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#IntName -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#IntName">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#InterfaceType"/>
<rdfs:range rdf:resource="&xsd:string"/>
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#IntProtocol -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#IntProtocol">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#InterfaceType"/>
<rdfs:range rdf:resource="&xsd:string"/>
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#IntType -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#IntType">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#InterfaceType"/>
<rdfs:range rdf:resource="&xsd:string"/>
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#InterfaceAddress -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#InterfaceAddress">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Interface"/>
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#InterfaceID -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#InterfaceID">
<rdf:type rdf:resource="&owl:FunctionalProperty"/>
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Interface"/>
<rdfs:range rdf:resource="&xsd:anyURI"/>
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#ModeID -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#ModeID">
<rdf:type rdf:resource="&owl:FunctionalProperty"/>

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<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Modes" />
<rdfs:range rdf:resource="&xsd:anyURI" />
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#ModeName -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#ModeName">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Modes" />
<rdfs:range rdf:resource="&xsd:string" />
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#NodeID -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#NodeID">
<rdf:type rdf:resource="&owl;FunctionalProperty" />
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Node" />
<rdfs:range rdf:resource="&xsd:anyURI" />
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#NodeTypeDescription -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#NodeTypeDescription">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#NodeType" />
<rdfs:range rdf:resource="&xsd:string" />
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#NodeTypeName -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#NodeTypeName">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#NodeType" />
<rdfs:range rdf:resource="&xsd:string" />
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#OperatingConstraints -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#OperatingConstraints">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#NodeType" />
<rdfs:range rdf:resource="&xsd:string" />
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#ProcessorID -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#ProcessorID">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Processor" />
<rdfs:range rdf:resource="&xsd:anyURI" />
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#Rechargeable -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#Rechargeable">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#EnergySource" />
<rdfs:range rdf:resource="&xsd:boolean" />
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#SerialNb -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#SerialNb">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Node" />
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#SourceType -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#SourceType">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#EnergySource" />
<rdfs:range rdf:resource="&xsd:string" />
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#TrustLevel -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#TrustLevel">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Node" />
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#baud -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#baud">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#InterfaceType" />
<rdfs:range rdf:resource="&xsd:integer" />
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#delay -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#delay">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#LinkState" />
<rdfs:range rdf:resource="&xsd:float" />
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#isGateway -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#isGateway">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Interface" />
<rdfs:range rdf:resource="&xsd:boolean" />
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#Actuator -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#Actuator">
<rdfs:subClassOf rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Node" />
<disjointWith rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Sensor" />
</Class>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#EnergySource -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#EnergySource" />
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#Hub -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#Hub">
<rdfs:subClassOf rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Node" />
</Class>

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<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#Interface -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#Interface">
  <rdfs:subClassOf>
    <Restriction>
      <onProperty rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#hasInterfaceType"/>
      <onClass rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#InterfaceType"/>
      <maxQualifiedCardinality rdf:datatype="&xsd;nonNegativeInteger">1</maxQualifiedCardinality>
    </Restriction>
  </rdfs:subClassOf>
</Class>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#InterfaceType -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#InterfaceType"/>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#LinkState -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#LinkState">
  <rdfs:subClassOf>
    <Restriction>
      <onProperty rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#hasLinkToNode"/>
      <onClass rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Node"/>
      <maxQualifiedCardinality rdf:datatype="&xsd;nonNegativeInteger">1</maxQualifiedCardinality>
    </Restriction>
  </rdfs:subClassOf>
</Class>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#MemoEnergy -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#MemoEnergy"/>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#Modes -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#Modes"/>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#Node -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#Node">
  <rdfs:subClassOf>
    <Restriction>
      <onProperty rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#hasMemoEnergy"/>
      <onClass rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#MemoEnergy"/>
      <maxQualifiedCardinality rdf:datatype="&xsd;nonNegativeInteger">1</maxQualifiedCardinality>
    </Restriction>
  </rdfs:subClassOf>
  <rdfs:subClassOf>
    <Restriction>
      <onProperty rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#hasNodeType"/>
      <onClass rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#NodeType"/>
      <maxQualifiedCardinality rdf:datatype="&xsd;nonNegativeInteger">1</maxQualifiedCardinality>
    </Restriction>
  </rdfs:subClassOf>
  <rdfs:subClassOf>
    <Restriction>
      <onProperty rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#inCurrentMode"/>
      <onClass rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Modes"/>
      <maxQualifiedCardinality rdf:datatype="&xsd;nonNegativeInteger">1</maxQualifiedCardinality>
    </Restriction>
  </rdfs:subClassOf>
</Class>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#NodeType -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#NodeType"/>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#Processor -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#Processor"/>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#Sensor -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/nodes#Sensor">
  <rdfs:subClassOf rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes#Node"/>
</Class>
</rdf:RDF>

```

B.3 Process.owl

```

<rdf:RDF xmlns="http://www.w3.org/2002/07/owl#"
  xml:base="http://www.w3.org/2002/07/owl"
  xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
  xmlns:owl="http://www.w3.org/2002/07/owl#"
  xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
  xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#">
<Ontology rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process"/>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#DataSize -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#DataSize">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Data"/>
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#DoAction -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#DoAction">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Action"/>
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#SampleRate -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#SampleRate">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Process"/>
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#calibration -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#calibration">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Process"/>
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#drift -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#drift">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Process"/>
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#hasConstraint -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#hasConstraint">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Constraint"/>
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Data"/>
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#hasData -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#hasData">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Data"/>
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Process"/>
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#hasDataType -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#hasDataType">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Data"/>
<rdfs:range rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#DataType"/>
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#hasDerivedData -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#hasDerivedData">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Data"/>
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Process"/>
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#hasFormat -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#hasFormat">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Data"/>
<rdfs:range rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Format"/>
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#hasInput -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#hasInput">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#I/O"/>
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Process"/>
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#hasMeasurement -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#hasMeasurement">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Data"/>
<rdfs:range rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Measurement"/>
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#hasOutput -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#hasOutput">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#I/O"/>
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Process"/>
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#latency -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#latency">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Process"/>
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#precision -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#precision">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Process"/>
</ObjectProperty>

```

```

<!-- http://www.engenoid.com/onto/TCSmartBAN/process#resolution -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#resolution">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Process"/>
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#responseorder -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#responseorder">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Process"/>
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#uom -->
<ObjectProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#uom">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Process"/>
</ObjectProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#AlgorithmVersion -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#AlgorithmVersion">
<rdfs:range rdf:resource="&xsd:string"/>
<rdfs:domain>
<Class>
<unionOf rdf:parseType="Collection">
<rdf:Description rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#Compression"/>
<rdf:Description rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#Security"/>
</unionOf>
</Class>
</rdfs:domain>
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#CompAlgorithm -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#CompAlgorithm">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Compression"/>
<rdfs:range rdf:resource="&xsd:string"/>
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#Key -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#Key">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Security"/>
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#KeyLength -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#KeyLength">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Security"/>
<rdfs:range rdf:resource="&xsd:integer"/>
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#MaxValue -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#MaxValue">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Validity"/>
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#MinValue -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#MinValue">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Validity"/>
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#ProcessID -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#ProcessID">
<rdf:type rdf:resource="&owl;FunctionalProperty"/>
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Process"/>
<rdfs:range rdf:resource="&xsd:anyURI"/>
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#QOS -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#QOS">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Data"/>
<rdfs:range rdf:resource="&xsd:int"/>
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#SecAlgorithm -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#SecAlgorithm">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Security"/>
<rdfs:range rdf:resource="&xsd:string"/>
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#TTL -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#TTL">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Measurement"/>
<rdfs:range rdf:resource="&xsd:int"/>
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#TimeStamp -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#TimeStamp">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Measurement"/>
<rdfs:range rdf:resource="&xsd:dateTime"/>
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#valid -->
<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#valid">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Measurement"/>
<rdfs:range rdf:resource="&xsd:boolean"/>
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#value -->

```

```

<DatatypeProperty rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#value">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Measurement" />
</DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#Action -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#Action" />
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#Compression -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#Compression">
<rdfs:subClassOf rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Constraint" />
</Class>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#Constraint -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#Constraint" />
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#Data -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#Data">
<rdfs:subClassOf>
<Restriction>
<onProperty rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#hasDataType" />
<onClass rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#DataType" />
<maxQualifiedCardinality rdf:datatype="&xsd;nonNegativeInteger">1</maxQualifiedCardinality>
</Restriction>
</rdfs:subClassOf>
<rdfs:subClassOf>
<Restriction>
<onProperty rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#hasFormat" />
<onClass rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Format" />
<maxQualifiedCardinality rdf:datatype="&xsd;nonNegativeInteger">1</maxQualifiedCardinality>
</Restriction>
</rdfs:subClassOf>
</Class>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#DataType -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#DataType" />
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#Document -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#Document">
<rdfs:subClassOf rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Legal" />
</Class>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#Format -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#Format" />
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#I/O -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#I/O" />
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#Legal -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#Legal">
<rdfs:subClassOf rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Constraint" />
</Class>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#Measurement -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#Measurement" />
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#Operating -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#Operating">
<rdfs:subClassOf rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Constraint" />
</Class>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#Process -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#Process" />
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#Right -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#Right">
<rdfs:subClassOf rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Legal" />
</Class>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#Security -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#Security">
<rdfs:subClassOf rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Constraint" />
</Class>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#Validity -->
<Class rdf:about="http://www.engenoid.com/onto/TCSmartBAN/process#Validity">
<rdfs:subClassOf rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process#Constraint" />
</Class>
</rdf:RDF>

```

B.4 Ontofull.owl

```

<rdf:RDF xmlns="http://www.engenoid.com/onto/ontofull#"
  xml:base="http://www.engenoid.com/onto/ontofull"
  xmlns:process="http://www.engenoid.com/onto/TCSmartBAN/process#"
  xmlns:nodes="http://www.engenoid.com/onto/TCSmartBAN/nodes#"
  xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
  xmlns:owl="http://www.w3.org/2002/07/owl#"
  xmlns:swrlb="http://www.w3.org/2003/11/swrlb#"
  xmlns:swrl="http://www.w3.org/2003/11/swrl#"
  xmlns:xsd="http://www.w3.org/2001/XMLSchema#"

```

```

    xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
    xmlns:wban="http://www.engenoid.com/onto/TCSmartBAN/wban#">
<owl:Ontology rdf:about="http://www.engenoid.com/onto/ontofull">
<owl:imports rdf:resource="http://qudt.org/1.1/schema/dimension"/>
<owl:imports rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/nodes"/>
<owl:imports rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/process"/>
<owl:imports rdf:resource="http://www.engenoid.com/onto/TCSmartBAN/wban"/>
</owl:Ontology>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#DutyCycle -->
<rdf:Description rdf:about="&nodes;DutyCycle">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#MIPS -->
<rdf:Description rdf:about="&nodes;MIPS">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#ModePower -->
<rdf:Description rdf:about="&nodes;ModePower">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#NodeDiscoveryTime -->
<rdf:Description rdf:about="&nodes;NodeDiscoveryTime">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#Position -->
<rdf:Description rdf:about="&nodes;Position">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Location"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#WakeupLatency -->
<rdf:Description rdf:about="&nodes;WakeupLatency">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#cost -->
<rdf:Description rdf:about="&nodes;cost">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#dimension -->
<rdf:Description rdf:about="&nodes;dimension">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#frequency -->
<rdf:Description rdf:about="&nodes;frequency">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#hasAvailableFlash -->
<rdf:Description rdf:about="&nodes;hasAvailableFlash">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#hasAvailableRAM -->
<rdf:Description rdf:about="&nodes;hasAvailableRAM">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#hasLinkState -->
<rdf:Description rdf:about="&nodes;hasLinkState">
<rdfs:domain rdf:resource="&nodes;Hub"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#hasMAXFlash -->
<rdf:Description rdf:about="&nodes;hasMAXFlash">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#hasMAXRAM -->
<rdf:Description rdf:about="&nodes;hasMAXRAM">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#hasRemainBattery -->
<rdf:Description rdf:about="&nodes;hasRemainBattery">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#inCoverage -->
<rdf:Description rdf:about="&nodes;inCoverage">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#outCoverage -->
<rdf:Description rdf:about="&nodes;outCoverage">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#receivingSensitivity -->
<rdf:Description rdf:about="&nodes;receivingSensitivity">

```

```

<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#velocity -->
<rdf:Description rdf:about="&nodes;velocity">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#DataSize -->
<rdf:Description rdf:about="&process;DataSize">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#DoAction -->
<rdf:Description rdf:about="&process;DoAction">
<rdfs:domain rdf:resource="&nodes;Actuator"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#SampleRate -->
<rdf:Description rdf:about="&process;SampleRate">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#calibration -->
<rdf:Description rdf:about="&process;calibration">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#drift -->
<rdf:Description rdf:about="&process;drift">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#latency -->
<rdf:Description rdf:about="&process;latency">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#precision -->
<rdf:Description rdf:about="&process;precision">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#resolution -->
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<!-- http://www.engenoid.com/onto/TCSmartBAN/process#responseorder -->
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<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/process#uom -->
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<rdfs:range rdf:resource="http://qudt.org/schema/qudt#Unit"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/wban#CommunicationPeriod -->
<rdf:Description rdf:about="&wban;CommunicationPeriod">
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<!-- http://www.engenoid.com/onto/TCSmartBAN/wban#Height -->
<rdf:Description rdf:about="&wban;Height">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity"/>
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<!-- http://www.engenoid.com/onto/TCSmartBAN/wban#HipCircumference -->
<rdf:Description rdf:about="&wban;HipCircumference">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/wban#MaxHR -->
<rdf:Description rdf:about="&wban;MaxHR">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity"/>
</rdf:Description>

<!-- http://www.engenoid.com/onto/TCSmartBAN/wban#RestingHR -->
<rdf:Description rdf:about="&wban;RestingHR">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/wban#WaistCircumference -->
<rdf:Description rdf:about="&wban;WaistCircumference">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/TCSmartBAN/wban#Weight -->
<rdf:Description rdf:about="&wban;Weight">
<rdfs:range rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity"/>
</rdf:Description>
<!-- http://www.engenoid.com/onto/ontofull#BelongTo -->
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<rdfs:domain rdf:resource="&nodes;Node"/>

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<rdfs:range rdf:resource="&wban;WBAN" />
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<owl:ObjectProperty rdf:about="http://www.engenoid.com/onto/ontofull#Contains">
<rdfs:range rdf:resource="&nodes;Node" />
<rdfs:domain rdf:resource="&wban;WBAN" />
<owl:inverseOf rdf:resource="http://www.engenoid.com/onto/ontofull#BelongTo" />
</owl:ObjectProperty>
<!-- http://www.engenoid.com/onto/ontofull#ElectHub -->
<owl:ObjectProperty rdf:about="http://www.engenoid.com/onto/ontofull#ElectHub">
<rdfs:range rdf:resource="&nodes;Hub" />
<rdfs:domain rdf:resource="&wban;WBAN" />
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<!-- http://www.engenoid.com/onto/ontofull#hasUnit -->
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<rdfs:domain rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity" />
</owl:ObjectProperty>
<!-- http://www.engenoid.com/onto/ontofull#isMeasuredBy -->
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<rdfs:range rdf:resource="&nodes;Sensor" />
<rdfs:domain rdf:resource="&process;Measurement" />
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<!-- http://www.engenoid.com/onto/ontofull#usedFor -->
<owl:ObjectProperty rdf:about="http://www.engenoid.com/onto/ontofull#usedFor">
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<rdfs:range rdf:resource="&process;Process" />
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<rdfs:range>
<rdfs:Datatype>
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<rdf:Description>
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</rdf:Description>
</owl:withRestrictions>
</rdfs:Datatype>
</rdfs:range>
</rdf:Description>
<!-- http://www.engenoid.com/onto/ontofull#hasValue -->
<owl:DatatypeProperty rdf:about="http://www.engenoid.com/onto/ontofull#hasValue">
<rdfs:domain rdf:resource="http://www.engenoid.com/onto/ontofull#Quantity" />
</owl:DatatypeProperty>
<!-- http://www.engenoid.com/onto/TCSmartBAN/nodes#Node -->
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</owl:Restriction>
</rdfs:subClassOf>
<rdfs:subClassOf>
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<owl:someValuesFrom rdf:resource="&process;Process" />
</owl:Restriction>
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<owl:maxQualifiedCardinality rdf:datatype="&xsd;nonNegativeInteger">1</owl:maxQualifiedCardinality>
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<owl:Restriction>
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<owl:maxQualifiedCardinality rdf:datatype="&xsd;nonNegativeInteger">1</owl:maxQualifiedCardinality>
</owl:Restriction>
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</owl:Restriction>
</rdfs:subClassOf>
</rdf:Description>
<!-- http://www.engenoid.com/onto/ontofull#Address -->
<owl:Class rdf:about="http://www.engenoid.com/onto/ontofull#Address">
<rdfs:subClassOf rdf:resource="http://www.engenoid.com/onto/ontofull#External" />
</owl:Class>
<!-- http://www.engenoid.com/onto/ontofull#BodySurface -->
<owl:Class rdf:about="http://www.engenoid.com/onto/ontofull#BodySurface">

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<rdfs:subClassOf rdf:resource="http://www.engenoid.com/onto/ontofull#Location"/>
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<rdfs:subClassOf rdf:resource="http://www.engenoid.com/onto/ontofull#Location"/>
</owl:Class>
<!-- http://www.engenoid.com/onto/ontofull#Implant -->
<owl:Class rdf:about="http://www.engenoid.com/onto/ontofull#Implant">
<rdfs:subClassOf rdf:resource="http://www.engenoid.com/onto/ontofull#Location"/>
</owl:Class>
<!-- http://www.engenoid.com/onto/ontofull#Location -->
<owl:Class rdf:about="http://www.engenoid.com/onto/ontofull#Location"/>
<!-- http://www.engenoid.com/onto/ontofull#LocationCoordinates -->
<owl:Class rdf:about="http://www.engenoid.com/onto/ontofull#LocationCoordinates">
<rdfs:subClassOf rdf:resource="http://www.engenoid.com/onto/ontofull#External"/>
</owl:Class>
<!-- http://www.engenoid.com/onto/ontofull#Quantity -->
<owl:Class rdf:about="http://www.engenoid.com/onto/ontofull#Quantity"/>
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History

Document history			
V1.1.1	December 2015	Publication	