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GROUP REPORT

Applications and use cases of Software Defined Networking (SDN) as related to microwave and millimetre wave transmission

Reference

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Foreword

This Group Report (GR) has been produced by ETSI Industry Specification Group (ISG) millimetre Wave Transmission (mWT).

Modal verbs terminology

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Executive summary

The present document presents and analyses some use cases for Software Defined Networking (SDN) focusing on the application of microwave (MW) and millimetre wave (mmW) transmission.

In particular millimetre wave technologies are considered a basic enabler for the future of telecommunication networks, for both access (5G mobile) and fronthaul/backhaul.

Fundamental aspects of those future networks are performance, flexibility and adaptivity far beyond what is possible today, with technologies like SDN and Network Functions Virtualization (NFV) providing the prerequisite capabilities.

The need for future mmW radio to coordinate with other transport and access technologies requires that the mmW ecosystem at least understand the scenarios and use cases in which the equipment will be integrated.

The goal of the present document is to provide an overview of applications and use cases that, leveraging on the SDN paradigm, are able to add value in terms of functionality, efficiency and/or cost when using microwave/millimetre wave network segments.

The peculiar characteristics of MW and mmW radio networks are to be taken into account in order to define the specific use cases and value propositions, which are both pertinent and compelling.

In perspective, an SDN network where a centralized intelligence can make the most of the huge amount of data coming from the current and past status of the entire network and its applications, will allow for innovative, dynamic and highly efficient services and operation, to levels not seen before.

Not secondary in this perspective is the promise of SDN to cross over equipment technology, network segment and vendor boundaries.

It is not in the scope of the present document to enter in any way into discussions about controller architectures, protocols, information models and implementation details since other specific Standard Defining Organizations (SDOs) are already in charge of these important issues.

In fact the present document is to be seen as complementary to the work done in other SDOs.

Introduction

The current architecture of telecom and data networks is based on the IP protocol stack, where the routing philosophy is made of *distributed control* and *hop by hop* decisions over single *data packets*.

This approach is beginning to show some limits in terms of performance, flexibility and scalability due to the exponential growth of data traffic that has been experienced for some years, in particular with the explosion of the quantity and quality of applications and terminals that require to be connected.

The requirements on the different traffic types range from high throughput to low latency, from high user density to high availability, from low power consumption to high reliability. The fulfilment of such a wide variety of requirements asks for a quite different network architecture, where adaptivity is fundamental.

In order to answer to this necessity several approaches have been proposed in the recent years, having in common the focus on the programmability offered by software:

- Cloud networking
- Network Functions Virtualization (NFV)
- Software Defined Networking (SDN)

In particular Software Defined Networking is an approach to networking based on the following principles:

- The separation of the data plane from the control plane
- The logical centralization of the control function

The routing philosophy introduced by SDN is based on *centralized control* able to perform *end-to-end* decisions over *data flows*.

The main concept is to have network elements with just forwarding functions, with on top a central controller which is able, on one side, to expose an abstracted view of the network resources to the applications and, on the other side, to allow an automated implementation of services independent from the physical details of the network.

As such this architecture is structured on three basic layers:

- Data plane, made of the different network elements (NEs)
- Control plane, which is the central controller
- Application plane, made of the different applications

The interface between control plane and data plane (SouthBound Interface, SBI) has the goal to allow for standard protocols to be implemented, two examples being OpenFlow and Netconf; in this way the goal would be to have a controller which is able to interact with NEs independently from the vendor specificity.

The interface between the application plane and control plane (NorthBound Interface, NBI) has the goal to allow Application Programming Interfaces (APIs) to be established so that applications can be developed independently from the particular physical network.

The specific SDN architecture is the object of several SDOs and is out of the scope of the present document. The focus of this work is to analyse and define use cases and applications in the domain of microwave (MW) and millimetre wave (mmW) transmission in which the SDN paradigm can be effectively applied.

1 Scope

The purpose of the present document is to provide information on the applications and use cases of the SDN paradigm as related to MW and mmW transmission.

The analysis covers the following *progressively widening ranges*:

1) The radio link network segment in itself.

2) The interactions of the radio link network segment with an adjacent segment.

3) The radio link network segment as a part of an end-to-end connection.

Even if going towards a wider network range the relevance of the MW/mmW segment may become less evident, nevertheless the relevance of SDN is at its highest level when considering end-to-end scope, where the MW/mmW segment is just a part of the whole picture but anyway requested to be able to adapt to the SDN requirements in order for services to be efficiently and effectively provisioned.

The classification of applications and use cases in the three aforementioned broad categories reflects a natural layering in terms of scope width, increasing complexity and increasing value, in terms of cost reduction, enabler for new revenue streams and enabler of innovations not yet thought of.

It has to be noted that several use cases described in a given network range (and clause) become part of the use cases described in the wider network range (and following clause) in a sort of recursive and *auto-similar* behaviour; it is anyway useful to keep the use case in all the relevant clauses in order to highlight the significant increase in value and decrease in cost that is achieved by extending the use case from segment towards end-to-end scope.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative 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 referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] Open Networking Foundation: "Wireless Transport SDN Proof of Concept White Paper".

NOTE: Available at https://www.opennetworking.org/images/stories/downloads/sdn-resources/white-papers/ONF_Microwave_SDN_PoC_White_Paper%20v1.0.pdf.

[i.2] Open Networking Foundation: "Wireless Transport SDN Proof of Concept 2 Detailed Report".

NOTE: Available at https://www.opennetworking.org/images/stories/downloads/sdn-resources/technical-reports/Wireless_Transport_SDN_PoC_White_Paper.pdf.

[i.3] Open Networking Foundation: "Third Wireless Transport SDN Proof of Concept White Paper".

NOTE: Available at https://www.opennetworking.org/images/stories/downloads/sdn-resources/technical-reports/Third-Wireless-Transport-SDN-Proof-of-Concept-White-Paper.pdf.

[i.4] NGMN Alliance: "NGMN 5G white paper".

NOTE: Available at http://www.ngmn.org/uploads/media/NGMN_5G_White_Paper_V1_0_01.pdf.

[i.5] SDN World Congress 2016: "Enabling 5G network slicing with programmable microwave transport".

NOTE: Available at http://www.layer123.com/sdn-webcast-mle123.

[i.6] IEEE™: "SDN-based architecture to support Synchronization in a 5G framework".

NOTE: Available at http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=7579504.

[i.7] "Securing the Cloud with SDN".

NOTE: Available at https://www.sdxcentral.com/articles/analysis/securing-cloud-sdn/2016/05/.

[i.8] Recommendation ITU-T G.8275.1: "Precision time protocol telecom profile for phase/time synchronization with full timing support from the network".

[i.9] Recommendation ITU-T G.8261: "Timing and synchronization aspects in packet networks".

[i.10] Recommendation ITU-T G.8262: "Timing characteristics of a synchronous Ethernet equipment slave clock".

[i.11] Recommendation ITU-T G.8264: "Distribution of timing information through packet networks".

[i.12] Recommendation ITU-T G.8272: "Timing characteristics of primary reference time clocks".

[i.13] Recommendation ITU-T G.8272.1: "Timing characteristics of enhanced primary reference time clocks".

[i.14] Recommendation ITU-T G.8273.2: "Timing characteristics of telecom boundary clocks and telecom time slave clocks".

3 Abbreviations

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

5G	Fifth Generation of Mobile Networks
API	Application Programming Interface
ATPC	Automatic Transmit Power Control
BC	Boundary Clock
BCA	Bands and Carrier Aggregation
BMCA	Best Master Clock Algorithm
BSS	Business Support System (customer facing activities)
BTS	Base Transceiver Station
CAPEX	Capital Expenditures
CIR	Committed Information Rate
CO	Central Office
CoMP	Coordinated MultiPoint
CPE	Customer Premises Equipment
DCN	Data Communication Network (management network for telecommunication systems)
DoS	Denial of Service
E2E	End-to-end
eMBMS	evolved Multimedia Broadcast Multicast Service
FTP	File Transfer Protocol
FWA	Fixed Wireless Access
GM	Grand Master
GPS	Global Positioning Service
IoT	Internet of Things
IP	Internet protocol
KPI	Key Performance Indicator

LOS	Line Of Sight
LTE	Long Term Evolution
LTE-A	Long Term Evolution - Advanced
M2M	Machine to Machine
mmW	Millimetre wave
MPLS	Multi Protocol Label Switching
MPtMP	MultiPoint to MultiPoint
MTBF	Mean Time Between Failures
MW	Microwave
n/NLOS	near/Non Line Of Sight
NaaS	Network as a Service
NBI	NorthBound Interface
NE	Network Element
NFV	Network Functions Virtualization
NMS	Network Management System
OAM	Operation Administration and Maintenance
ONF	Open Networking Foundation
OPEX	Operational Expenditures
OSS	Operational Support System (network facing activities)
PIR	Peak Information Rate
PMP	Point to MultiPoint
PoC	Proof of Concept
PoP	Point of Presence
PTP	Precision Time Protocol
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RF	Radio Frequency
SBI	SouthBound Interface
SDN	Software Defined Networking
SDO	Standard Defining Organization
SLA	Service-Level Agreement
SON	Self Organizing Network
SW	SoftWare
TDD	Time Division Duplex
TTM	Time To Market
UL/DL	Uplink/Downlink
VLAN	Virtual LAN
VPN	Virtual Private Network
WttC	Wireless to the Cabinet
WttH	Wireless to the Home

4 Applications and use cases: overview

4.1 Differentiators of MW/mmW technology

The main peculiarities of the wireless transport networks which differentiate them from other transport technologies (for example optical and/or packet) are:

1) Dynamic nature of the communication channel, due for instance to interference, rain attenuation, multipath fading.

2) Huge number of nodes per area to be controlled (scalability). This places an issue on the stability of the controlled network, since control information has to reach each node avoiding oscillations, information storms and inconsistencies.

3) Limited time scale of control channel (DCN bandwidth), due to current use mainly for configuration and monitoring.

4) Street-level peculiarities, for instance multipath, pole oscillations, temporary obstructions, power availability.

5) Low number of functions to be virtualized.

6) Mostly non-redundant paths (tree/chain topologies, usually no rings/meshes), even if innovative traffic management systems implemented thanks to SDN may make rings/meshes attractive in the wireless backhaul.

7) Spectrum use regulation limits what can be automated in RF planning, automated antenna pointing, etc.

8) Transmission bandwidth impacts power consumption in a very limited way (unless turning on/off a complete carrier).

4.2 Considerations on time scale

The actions of an SDN controller can be fundamentally grouped into 2 categories:

1) Actions triggered by events happened in the network

2) Actions not directly dependent on a specific network event

In the first case, the main parameters to be considered are:

- Event speed
- Event duration
- Event frequency

The reaction time of the SDN system is dependent on different factors:

- Time for notification to be received by the controller
- Elaboration time in the controller
- Time for command to be received by the network elements

The geographical scope and the bandwidth of the control channel can set in some cases the lower limit to the reaction time of the controller, depending on the location of the controller and on the technology used for the control channel.

The second type of SDN action is asynchronous from any network event and comprises for example:

- Network (re)configuration
- Provisioning of new services
- Continuous network optimization

In general at least four different time scales can be identified:

1) Events requiring very fast (typically hardware) action on the single NE (e.g. protection switching).

2) Events requiring quite fast (typically software) action on the single link (e.g. adaptive modulation and coding, ATPC).

3) Events requiring relatively slow (typically software) action (e.g. load balancing due to instantaneous traffic load and link status).

4) Events requiring very slow (typically software) action (e.g. slow interference events, long-time-scale traffic patterns).

The capacity of the control plane, the DCN resources and the required time scale of consequent reaction are expected to restrict the application scope of SDN to events of the last two types, i.e. with a sufficiently long time scale for notification, elaboration and reaction. As a general reference a discriminating time scale for SDN to be able to effectively operate is on the order of seconds, whilst sub-second variations are out of SDN scope.

Moreover it has to be highlighted that whenever the NE is able to perform a proper reaction locally on its own there is no reason for a centralized control system to be involved.

Time scale	Functional examples	SDN applicability
Very fast	Protection switching	No
Quite fast (sub-second)	Adaptive modulation, traditional ATPC	No
Relatively slow (seconds)	Dynamic adaptation to link and/or traffic variations	Yes
Very slow/static	Slow events, configuration, OAM, QoS	Yes

5 Applications and use cases: description

5.1 Radio link network segment in itself

5.1.1 Introduction

The use cases of this clause are characterized by the fact that all information and action are contained within the MW/mmW radio network domain.

There is no coordination with other technologies or other network layers (e.g. the RAN), even if the information about the status and the events in the mmW radio layer can be made available and used by any other entity in the SDN ecosystem.

5.1.2 Efficient power consumption

Energy saving is one major goal of both current and future networks.

In addition to specific power-saving mechanisms that can be built in the equipment hardware, more sophisticated mechanisms and their activation can be devised and controlled by a centralized application, based on deep data analysis from historical and current network configurations and load conditions.

Such mechanisms can include activation/deactivation of carriers in multi-carrier systems, advanced low-power states and even intelligent power down of parts of the network (with reconfiguration of the remaining radio network).

As an example consider a high power long haul link made of 4 carriers. Each carrier consumes around 40 to 50 Watts; overall the 4 carriers consume about 200 Watts. In the case that during night time capacity drops to ¼ of the peak, 150 Watts can be saved. With a traffic profile that looks like:

Time of Day	Amount of traffic versus peak
5:00 to 8:00	50 %
8:00 to 10:00	75 %
10:00 to 16:00	100 %
16:00 to 20:00	75 %
20:00 to 24:00	50 %
24:00 to 5:00	25 %
Daily Average	63,54 %

In this case power savings in the order of 36 % can be achieved.

Carrier activation/deactivation in multi-carrier systems triggered by the traffic level has been demonstrated in ONF PoC of October 2015 under the name "capacity driven air interface" [i.1].

Value	• Save OPEX without impacting service • Meet energy efficiency targets • Optimize equipment cost • Easy target to start working on smart network power consumption management
Specific needs to be addressed	• Reduce power consumption • Reduce equipment wear
Applicability	• Multi-directional hub, multi-carrier/multi-channel radio links
Time scale of events	• A few hourly events
Reaction time of SDN	• Tenths of seconds
Specific contribution to/from SDN	• Centralize control of this function, using network-wide data (also across other domains) to perform data analysis, prediction and optimize the power-off time • Easy integration with other transport technologies
Potential issues/problems	• Repeated power cycling effect on MTBF • Reliability of the restart process • Data analysis & prediction algorithm efficiency
Related/dependencies	• More comprehensive energy saving schemes at network level (see clause 5.2.6) • ONF PoC capacity driven air interface, October 2015 [i.1]

5.1.3 Dynamic traffic distribution

Ring and mesh topologies have not been used very much in the past for MW and mmW networks, mostly due to the centralized architecture of 2G and 3G networks, where no communication among peripheral sites was required. Therefore, using ring or mesh topology was only done for geographical network protection, restricting their economic attractiveness. Due to the flexibility introduced by packet transmission and to the new and increasing connectivity requirements among peripheral nodes (e.g. LTE X2), ring and mesh topologies are expected to enjoy a new popularity.

Thanks to the automation and the optimization made possible by an SDN system using big data analytics about the network conditions, mesh architectures could provide the throughput, adaptability and resiliency that are increasingly demanded from the networks. A significant example is providing small cell backhaul in a dense urban scenario at street level.

When more than one path exists across the network, traffic can be dynamically distributed over the available links in order to:

1) Maximize throughput based on link topology and actual capacity as triggered by a variation in traffic.

2) Provide resiliency by reacting to capacity changes (e.g. adaptive modulation), load changes, link interruptions (e.g. LOS transient blockage at street level), transient interference problems or link failures.

3) Provide synchronization redundancy.

   Due to certain mobile access features requirements (e.g. inter-site carrier aggregation, CoMP, etc.), phase/time synchronization is required. One of the many available options is backhaul networks (including also radio links) to support the relevant ITU-T Packet Synchronization Recommendations, such as Recommendation ITU-T G.8275.1 [i.8]. A key to the resiliency of the Precise Time Protocol (PTP) is the Best Master Clock Algorithm (BMCA), which specifies the way by which each clock determines the best master clock in its sub-domain out of all clocks it can see, including itself. In case of synchronization failure (e.g. due to a faulty unit), an SDN controller could make the necessary computations and decide on-the-fly, which should be the new master clock for a given PTP-aware node (assuming a topology that allows such an action).

4) Provide flow handling (e.g. video distribution/multicast).

   Backhaul networks (including also radio links) benefit from multicast connections that are established for specific type of services, since available bandwidth is consumed in a more efficient manner. Evolved Multimedia Broadcast Multicast Service (eMBMS) is only an indicative example, in which data is transmitted from a single source entity to multiple recipients. The nature of such services is not constant, but they should be available when a group of users (authorized subscribers) initiate the relevant requests to the network. An SDN controller could decide and apply on-the-fly a multicast connection (service provisioning), when there is such a need and where (namely, on which radio links) it is needed.

Value	• Save OPEX by establishing automatic: – network (re)-configuration – NEs integration (including service provisioning) – network healing especially as network density increases • Make meshing economically convenient even in rooftop-to-rooftop scenarios
Specific needs to be addressed	• Enabler for wireless meshing • Increase dynamic traffic load management • Increase network resilience • Ensure network synchronization, e.g. for specific mobile broadband services • Handling more granular flows - looking into flows inside the VLAN that reaches the base station to allow better load balancing and more efficient service delivery • Provide additional reliability in harsh scenarios (street level, propagation and interference effects) thanks to path redundancy and multi-homing • Gracefully degrade network/service performances in case of node failures • Use sophisticated algorithms for the slower events
Applicability	• Ring or mesh topologies
Time scale of events	• Fast street level events: milliseconds • Street level events: seconds/minutes • Atmospheric events: minutes/tens of minutes • Topology changes: some events per year, hours
Reaction time of SDN	• Seconds
Specific contribution to/from SDN	• This is a basic building block for more and more sophisticated SON systems, exploiting the cross-domain and cross-technology potential of SDN • Radio planning can be based on complex policies controlled centrally • Optimize traffic load distribution network-wide
Potential issues/problems	• Fast events may not allow use of an SDN approach
Related/dependencies	• More comprehensive optimization schemes at network level (see clauses 5.2.5 and 5.3.3) • Interference handling (see clause 5.1.4) and radio planning

5.1.4 Interference handling

Interference is a major issue, in particular when considering the densification trend required for the coverage and backhauling of hot spots and dense urban deployments.

Countermeasures to transient or permanent interference include:

- In frequency domain, re-planning of the RF channel assignments (see clause 5.1.6).
- In digital/algorithm domain, re-configuration of beam-forming antennas (beam-nulling techniques).
- In space domain, adapting traffic distribution (see clause 5.1.3).
- In service domain, adapting some parameters (e.g. CIR and PIR rates for specific flows) to the new conditions.

As an example in MW and mmW links, interference can be dominant when weather conditions degrade one signal, but not the interfering one.

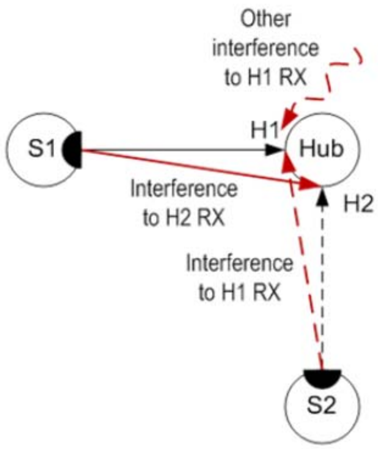

Figure 1: Interference scenario

In figure 1, the link S1-H1 can suffer from a fade while S2 - H2 does not. In this case during the fade the interference to H1 can be more dominant than in clear sky.

SDN can mitigate this scenario in different ways:

1) During the fade when the interference is dominant, the SDN controller will temporary reduce the bandwidth of S1-H1 and S2-H2 by half, each using different half of the spectrum. This will eliminate the interference, and the temporal capacity will drop by 2. When fade disappears, SDN can return to the original bandwidth allocation.

2) During the fade at S1-H1, the SDN controller will allocate a temporary channel for the fade duration from a pool of "spare" channels. This channel will return to the pool when the fade event is gone. The main idea is that fades do not happen at the same time in all links, so small amount of channels in the pool can be enough.

3) During the fade the SDN controller will command a scanning of the frequency domain in order to select the best channel (see clause 5.1.6).

It is to be highlighted that regulatory issues (licensing) are a fundamental pre-requisite for the applicability of this use case.

Value	• Reduce OPEX due to better frequency reuse (no re-planning) • Reduce OPEX due to less frequent troubleshooting • Reduce OPEX due to less frequent re-configuration
Specific needs to be addressed	• Use spectrum in the most efficient way (e.g. optimizing a block allocation) • Resilience towards interference by same type systems and by heterogeneous systems (e.g. 60 GHz P2P, WiGig, etc.) • Fastest rollout of new links, thanks to the automation of the RF coordination • Better frequency reuse • Change bandwidth and channel on the fly (regulation permitted) • More sophisticated algorithms in case of MPtMP deployments
Applicability	• Just in unlicensed or area block licensing regulation
Time scale of events	• Sub-seconds/milliseconds
Reaction time of SDN	• Seconds
Specific contribution to/from SDN	• Automatic frequency channel change to be controlled by SDN at MW/mmW network level, using network-wide data to perform data analysis, prediction and to optimize the channels and the bandwidth
Potential issues/problems	• Regulation • Fast events may not allow use of an SDN approach (probably smaller SDN clusters) • Avoid service impact on adjacent links of the same frequency band • Challenges of MPtMP deployments/planning
Related/dependencies	• Automated frequency allocation (see clause 5.1.6) • Dynamic traffic distribution (see clause 5.1.3)

5.1.5 OAM of MW/mmW networks

OAM functions are currently implemented by means of a complex set of proprietary systems (NMS/OSS/BSS). A big challenge that can be addressed by means of SDN is to coordinate them in order to manage the entire mmW/MW network, which is usually multi-vendor.

Among the many functions performed by such systems are:

- Fault and alarm management
- Configuration management
- Administration, authentication and accounting management
- Performance management
- Security management
- Inventory management
- Service provisioning
- Troubleshooting and root-cause analysis
- Multilevel network optimization
- User-friendly visualization of network and services

Some of these use cases have been demonstrated in ONF PoC of April 2016 [i.2]:

- Detection and configuration of new MW devices
- Detection and visualization of the configured/currently effective MW network
- Receiving, displaying and storing of alarm information

Value	• Reduce OPEX and CAPEX due to less complex NMS/OSS/BSS architecture • Less OPEX due to more efficient network management • Less OPEX due to less frequent and faster troubleshooting (more efficient collaboration across different technology teams) • Faster TTM (expedited services provisioning) • Increase customer satisfaction (quicker services provisioning, reduced time to resolve issues)
Specific needs to be addressed	• Allow SDN applications to discover and configure the mmW/MW equipment - Faster NE integration, acceleration of services provisioning • Enhanced Inventory management - guarantee that Operations have a correct and up-to-date picture of the existing network's structure and configuration • Better quality & quantity of alarms - root cause analysis considering entire mmW/MW network status • Intelligent Performance management with relevant KPIs • Increase operational efficiency and reduce potential for human error
Applicability	• All networks
Time scale of events	• Fault and performance management: many 1 000 events per day • Most other events: from few to 100s of events per day
Reaction time of SDN	• Strongly dependent from the specific function, existing NMS performance can be used as a baseline
Specific contribution to/from SDN	• Allow these functionalities to be implemented in truly vendor independent fashion
Potential issues/problems	• Interaction with the NMS to be clarified • Level of automation, e.g. root-cause analysis algorithm and troubleshooting actions, software upgrade, etc.
Related/dependencies	• ONF PoC of April 2016 [i.2]

5.1.6 Automated frequency allocation

This use case can be applied to different spectrum allocation scenarios:

1) *Block assignment* to an operator. In case an operator has an exclusive block allocation, the SDN controller can be in charge of triggering frequency change within the block in order to minimize interference (e.g. changing channel on interfered link) and/or to optimize traffic needs (e.g. enlarging channel on congested link).

2) *Light licensing assignment*. The SDN controller compares the configured channel with the planned channel (querying an administration/ spectrum provider data base) and in case of mismatch triggers an alarm message and a frequency change.

3) *Unlicensed assignment*. In this scenario an SDN controller can be in charge of triggering a frequency change in order to minimize interference.

This use case has been demonstrated in ONF PoC of October 2016 under the name spectrum management [i.3].

Value	• OPEX saving due to automatic network optimization
Specific needs to be addressed	• Self-coordination of radio channel allocations, in order to minimize interference and maximise throughput • Efficiently address temporary situations (e.g. specific or increased coverage of sporting events, etc.)
Applicability	• All cases where the operator is allowed to self-select the operating channels thanks to the spectrum licensing scheme
Time scale of events	• Seconds (e.g. transient interference conditions), days/weeks (transient network/traffic conditions), indefinite (e.g. permanent changes to own or interfering network)
Reaction time of SDN	• It should at least address the longer duration events, fast events (seconds or below) may be managed by the NE-resident software (SON, etc.)
Specific contribution to/from SDN	• Flexibility, programmability and automation
Potential issues/problems	• Network stability, resolution of conflicting needs, interaction with operators' actions in case of lightly or unlicensed cases
Related/dependencies	• ONF PoC of October 2016 [i.3] • Interference handling (see clause 5.1.4)

5.2 Radio link network segment and one adjacent network segment

5.2.1 Introduction

In current mobile networks, the RAN and the backhaul segments work independently from each other. In an SDN approach a holistic view can be employed with several advantages:

- being aware of backhaul path load and capacity, RAN can distribute its flows in order to prevent congestion in transport segment and optimize the user experience;
- being aware of RAN traffic patterns, transport segment can adapt its resources in order to distribute traffic in a balanced way.

Besides RAN, also aggregation/metro segment is adjacent to microwave backhaul; in this case the SDN inter-domain approach can involve multi-technology (microwave/optical) and/or multi-layer (L1/L2/L3).

Finally it is important to highlight that the radio link network segment is not used only in *mobile* networks but in *fixed access* networks as well, both as a final connection to the user equipment (WttH) and as backhaul connection from the aggregation point (WttC). Here as well a holistic approach with SDN controlling both user-to-cabinet and cabinet-to-backbone connections can give significant added value.

These use cases extend the scope of the ones detailed in the previous clause, not only by coordinating with what happens at link-level, but also opening new possibilities thanks to the joint use of information and actions belonging to multiple domains.

5.2.2 Adaptive resource allocation in the RAN based on the transmission network status

The transmission network status can be affected by propagation conditions (adaptive modulation changes, n/NLOS capacity fluctuations, addition/deletion of new radio links, changing interference conditions, LOS interruptions at street level, and more).

Based on the current or forecast condition of the backhaul network, the RAN can optimize the resource assignment to individual users, among several users, to individual RATs, etc., for example handing a user over to a cell that may not be optimal from a strictly RAN point of view, but makes optimal use of the backhaul network, or modifying the X2 adjacencies based on the capacity and latency conditions of the backhaul network.

An example is given by backhaul based load balancing, in which a mobile user in RAN is redirected to a different base station in order to distribute in a better way the traffic load between two backhaul links.

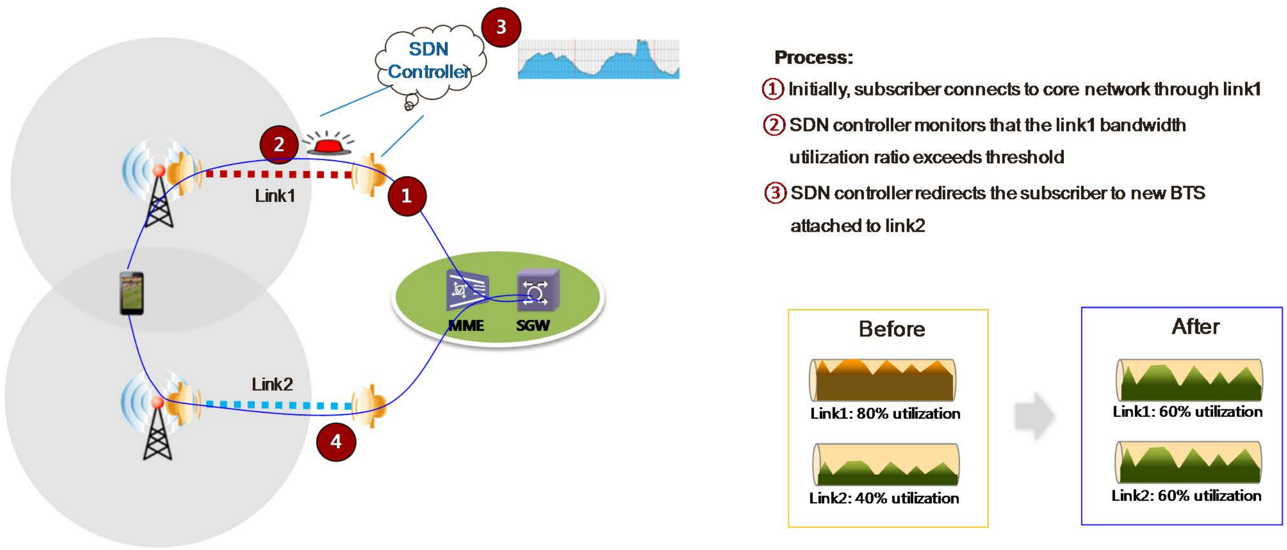

Figure 2: Load balancing (backhaul generated)

Value	• Always keep up customer QoE
Specific needs to be addressed	• Optimization of backhaul resources allocation
Applicability	• All cases in which more than one E2E path exists to reach the end mobile customer
Time scale of events	• Sub seconds
Reaction time of SDN	• Seconds
Specific contribution to/from SDN	• Coordinated management across different domains
Potential issues/problems	• Need to work with 3GPP on interface definition (standardization)
Related/dependencies	• RAN algorithms for such optimizations

5.2.3 Adaptive resource allocation in the transmission network based on RAN traffic patterns

The transmission network can adapt and optimize its configuration, based on the current or forecast conditions of the RAN. These may change in time and space due to several reasons, like day/night and other seasonal traffic cycles, extemporary events (sporting events, natural disasters and other emergencies), network transformation (addition/deletion/modification of mobile sites), etc.

This includes e.g.

a) Adapt the number of active carriers in a carrier aggregation backhaul link

b) Adapt L2/L3 VPNs to X2 changing requirements

c) Optimize the QoS configurations based on the traffic type and demand

d) Activate multicast type of connections due to specific services requirements

Value	• Always keep up customer QoE
Specific needs to be addressed	• Optimization of backhaul resources allocation • Fulfil mobile access services requirements (e.g. Inter-site carrier aggregation, eMBMS, etc.) in a dynamic fashion • Backhaul QoS optimization, namely no limit on lower priority services, in case more bandwidth is demanded at given time, while higher priority services will not be jeopardized at the same time
Applicability	• All mobile backhaul scenarios
Time scale of events	• Strongly dependent on the specific event/action (e.g. daily traffic load patterns, semi-permanent X2 neighbourhood relation updates, etc.)
Reaction time of SDN	• Strongly dependent on the specific event/action, not expected to be below the minute scale
Specific contribution to/from SDN	• Coordinated management across different domains
Potential issues/problems	• Network stability, overall vs. local optimization
Related/dependencies	• RAN-related optimization/configuration mechanisms, multi-layer optimization

5.2.4 Flow-based shaping

Link quality degradation on the wireless link can occur because of different reasons, for instance fading, which will lead to traffic congestion. Once a congestion situation is generated, all the connections traversing the bottleneck suffer from buffering (delay and jitter) and, in the worst case, packet dropping (loss). Sophisticated QoS handling capabilities are not commonly available today at the wireless transport equipment. Furthermore, the load in the network can benefit from an early application of shaping deep in the network for those flows traversing congested paths.

Thus, it is important to have in place mechanisms that dynamically adapt high throughput flows to the transport capacity currently available in the relevant section of the backhaul network.

This use case is centered on control of both wireless transport and switching equipment from the same SDN controller.

An Ethernet service flow is configured through the wireless transport NE and a router ahead of it. The controller gets the current link capacity by polling or receiving notification from the wireless transport NE. When the current capacity falls under a threshold, the controller will enable the corresponding shaper on the router. When the current capacity returns above the threshold, the controller will disable the shaper on the router.

This use case, which applies across microwave and packet domains, has been demonstrated in ONF PoC of October 2015 [i.1].

Value	• Reduced OPEX due to real-time network adaptation
Specific needs to be addressed	• Centralized congestion handling • Optimal network performance
Applicability	• All cases in which the MW/mmW link is connected to a higher capacity equipment capable of port shaping or even traffic throttling
Time scale of events	• For rain fading cases, minutes
Reaction time of SDN	• Seconds/minutes
Specific contribution to/from SDN	• Coordinated management across different domains
Potential issues/problems	• Unwanted packet loss in case of slow reaction to fast events
Related/dependencies	• Dynamic traffic routing can be combined • ONF PoC of October 2015 [i.1]

5.2.5 Dynamic traffic routing

This use case is an extension of the one described at radio link level (see clause 5.1.3), with much higher possibilities of efficiency.

Each relevant traffic type/flow can be dynamically routed over the available network resources based on the topology, traffic load and network capacity. In case a wireless link has a capacity degradation, for instance due to fading, the controller can instruct a router ahead of the MW link to re-direct part of the traffic towards an alternative route, preventing network congestion and packet loss.

A proper combination of shaping and re-routing is also possible on the base of flow priority, allowing for example high priority/low latency traffic to go ahead on the MW link with some shaping and redirecting low priority/best effort traffic on alternative routes with possibly higher delay.

This use case applies across microwave and packet domains.

Value	• Reduced OPEX due to real-time network adaptation
Specific needs to be addressed	• Centralized congestion handling • Optimal network performance
Applicability	• All cases when more than one path exists to a given base-station (mobile) or access point (FWA)
Time scale of events	• Should not react to conditions shorter than at least minutes scale
Reaction time of SDN	• Minutes or longer
Specific contribution to/from SDN	• Coordinated management across different domains
Potential issues/problems	• Network stability, local vs. overall optimization
Related/dependencies	• Flow based shaping can be combined • Extension of dynamic traffic distribution at radio link level

5.2.6 Efficient power consumption

This use case is an extension of the one described at radio link level (see clause 5.1.2), with much higher possibilities of efficiency.

According to traffic patterns in RAN and traffic load in transport, both in time and space domains, the not used parts of the network can be accordingly switched off in order to minimize power consumption.

Coordination between the RAN and the transport can increase the effectiveness and the reliability of such measures. The SDN framework will enable advanced analysis and forecast capabilities and the implementation flexibility that make such features very hard to deploy today.

For example according to the daily known distribution of mobile traffic, the RAN and the backhaul can selectively switch off part of their access and transmission resources during off-peak time; they will be switched on before peak time to avoid impact on service delivery.

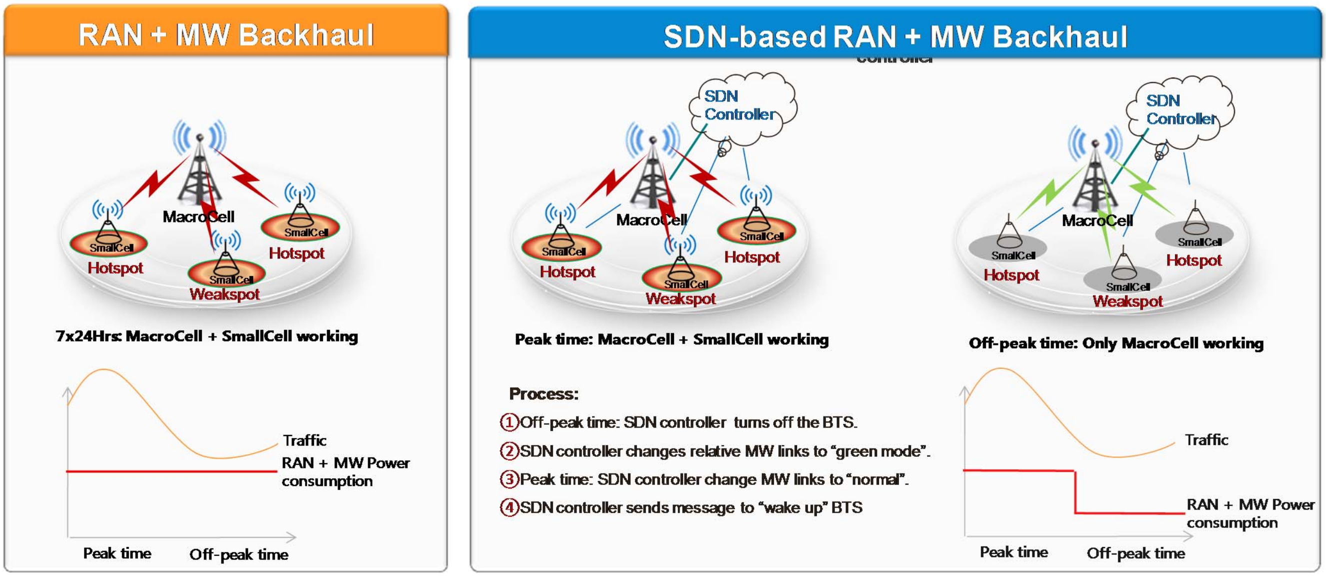

Figure 3: Energy efficiency (joint RAN-backhaul)

Value	• Save OPEX without impacting service • Meet energy efficiency targets • Optimize equipment cost • Easy target to start working on smart network power consumption management
Specific needs to be addressed	• Reduce power consumption • Reduce equipment wear
Applicability	• All networks
Time scale of events	• A few hourly events
Reaction time of SDN	• Tenths of seconds
Specific contribution to/from SDN	• Centralize control of this function, using network-wide data (also across other domains) to perform data analysis, prediction and optimize the power-off time • Easy integration with other transport technologies
Potential issues/problems	• Repeated power cycling effect on MTBF • Reliability of the restart process • Data analysis & prediction algorithm efficiency • No compromise on RAN performance (after turn BTS off and considering time needed for BTS to be fully up and running)
Related/dependencies	• Extension of efficient power consumption at radio link level (see clause 5.1.3) • More comprehensive energy saving schemes at end-to-end level

5.2.7 Self-backhaul

5.2.7.1 Introduction

Self-backhaul is defined as the situation in which the access and the backhaul segments share the same wireless channel. It is used in 3GPP LTE for PtP relaying at Layer 3.

In the framework of 5G networks, the same mmW spectrum may be allocated dynamically to access, fronthaul and backhaul depending on user location, traffic demand, interference and propagation conditions; mmW transport is particularly suited to self-backhaul due to its inherent high degree of spatial separation (directional beams) and wide available bandwidth.

SDN could be employed in order to handle the management of the shared radio resources (frequency, time and space):

- Dynamic spectrum sharing, that is assigning the available frequency channels to access, fronthaul and backhaul according to the traffic and/or channel conditions.

- Dynamic scheduling, that is assigning the available time slots to access, fronthaul and backhaul according to the traffic and/or channel conditions.

- Dynamic management of the antenna beams (in case a beam-steering capable system is deployed) in order to minimize interference by proper spatial separation.

Dynamic scheduling most likely requires action times not easily feasible in an SDN approach.

5.2.7.2 Self-backhaul with mobile access

A possible example of self-backhauling employing both dynamic spectrum sharing and antenna beam management is mobile access in the dense street level scenario: small cells are deployed in the urban clutter as a capacity layer, dedicated backhaul is provided between small cells and street-level fibre points of presence by LOS wireless. In the event of a link (or fibre node) failure, the self-backhauling mode is implemented. An SDN controller can calculate the best connectivity option(s) based on a range of parameters such as throughput, latency, loading, etc. and use antenna capability on the cell to build a temporary link to replace the failed link(s). Spectrum is allocated from that available to the small cell. A number of resource blocks are allocated to these links whilst other radio interface optimisations take place to manage overall user experience, which includes the implementation of QoS, rate capping and load based handover, as appropriate. This requires a tight integration between the radio access network and backhaul network along with both local and distributed intelligence.

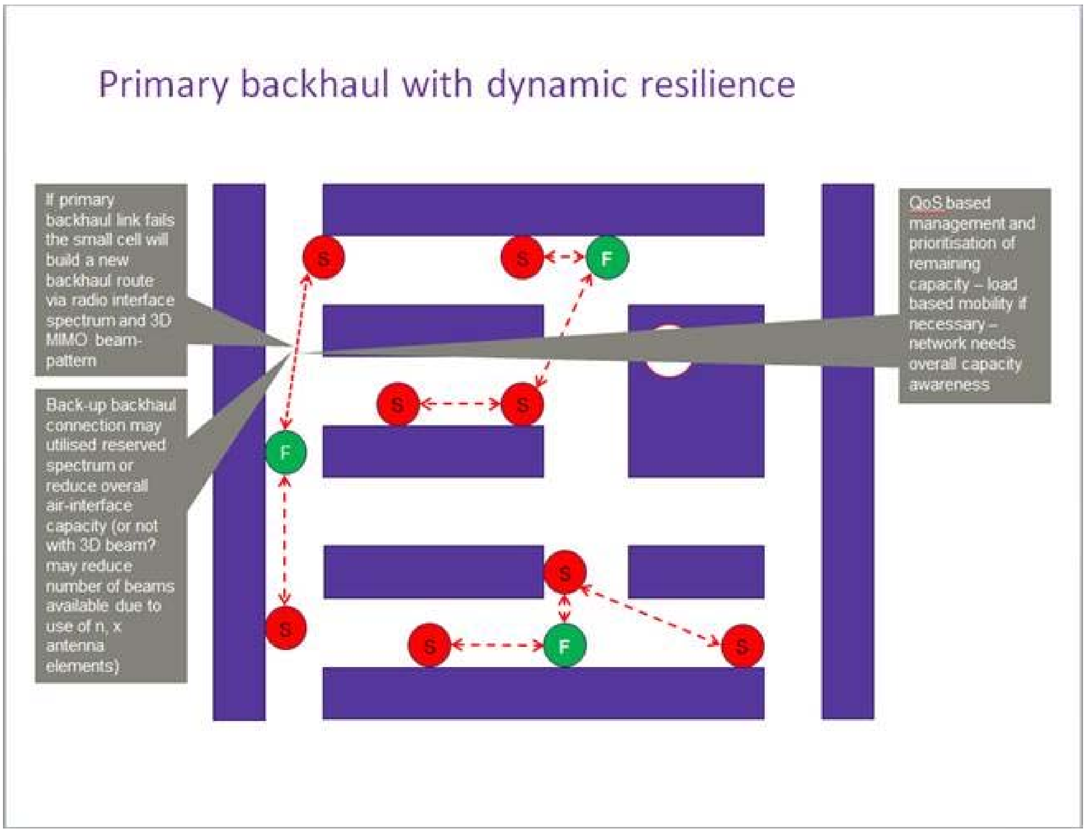

Figure 4: Example of self-backhaul with mobile access in dense urban scenario

5.2.7.3 Self-backhaul with fixed wireless access

A similar paradigm could be also followed and developed for the Fixed Wireless Access (FWA) application. As per the WttH use case, an aggregation access node could be installed at street level, for instance at a street cabinet or at a lamp post with easy connectivity to existing transport network. The aggregation access node communicates over the air with one or more remote access nodes that are installed outside residential buildings. The access aggregation node is connected to the existing transport network via local fibre connectivity or even by deploying a few hops before reaching the closest fibre-enabled PoP. The remote access nodes provide direct physical connectivity to the in-house CPE, so that the authorised end-user services are delivered.

As per figure 5, remote access node at location C is served from an aggregation access node at location B, which has a primary backhaul link established to location A.

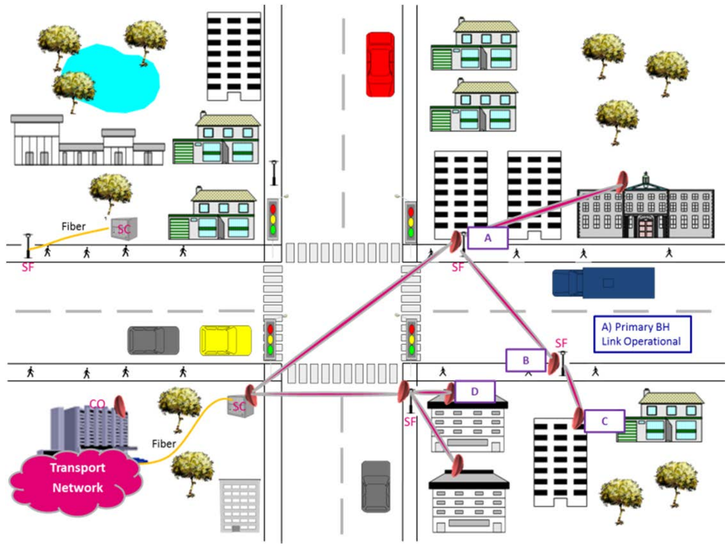

Figure 5: Example of self-backhaul with FWA: initial situation

Assuming that backhaul link between locations A and B breaks (as per figure 6), then the user(s) at location C stop enjoying the requested services until primary backhaul link is restored.

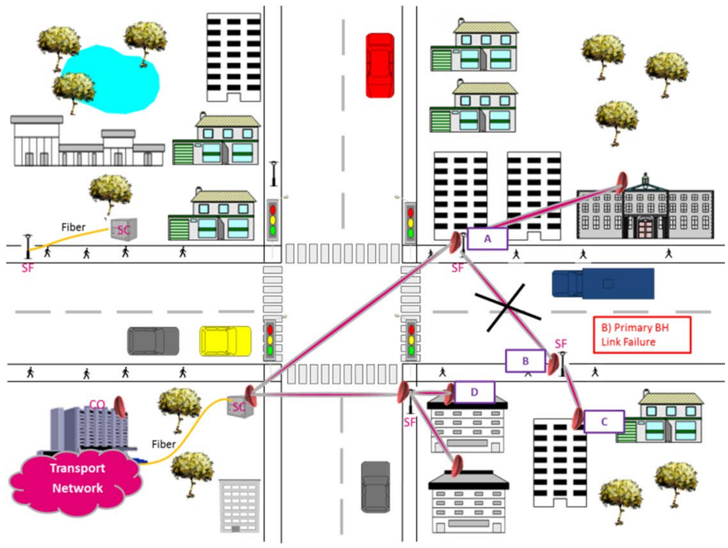

Figure 6: Example of self-backhaul with FWA: backhaul failure

Alternatively, an SDN controller could track alternative routes for aggregation access node at location B taking into consideration radio physical parameters and by computing available resources of the fixed access spectrum. By this regard, an SDN controller could dynamically dictate aggregation access node at location B to connect to an adjacent access aggregation node (for example, at location D as per figure 7) by establishing the most efficient available backup link rapidly, resulting to increased service availability and non-compromised QoE.

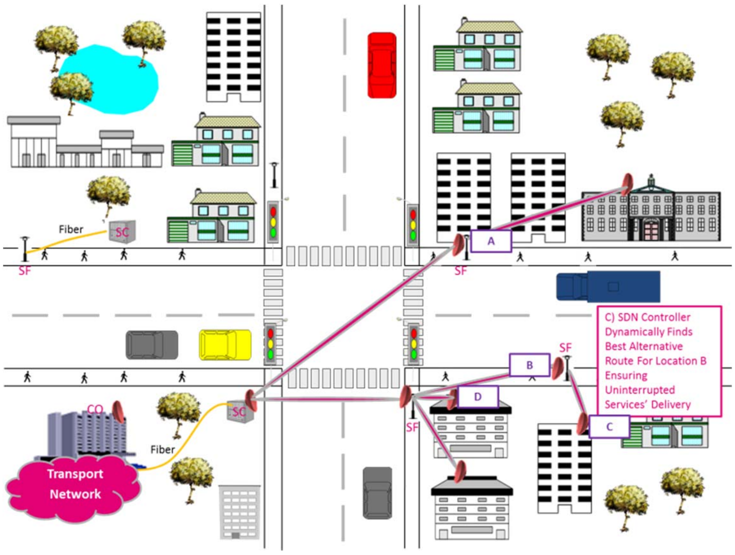

Figure 7: Example of self-backhaul with FWA: self-backhaul restoration

Value	• CAPEX and OPEX savings due to less equipment needed • OPEX saving due to more efficient spectrum usage
Specific needs to be addressed	• Fulfil 5G access services with optimal sharing of backhaul spectrum (regulation permitted) • No need to change frequency band • Increased services' availability
Applicability	• All networks that can share access and backhaul spectrum
Time scale of events	• Fast street level events: milliseconds • Street level events: seconds/minutes • Atmospheric events: minutes/tens of minutes • Topology changes: some events per year, hours
Reaction time of SDN	• Seconds or minutes
Specific contribution to/from SDN	• Integrate access and backhaul automatic optimization
Potential issues/problems	• Standardization (e.g. 3GPP)
Related/dependencies	• Fixed broadband

5.2.8 Fixed Broadband - Wireless to the Home (WttH)

MW/mmW technology can be used to provide wireless fixed broadband service directly to end users. Interference management (self organization), resource/SLA management based on customer-specific policies and/or conditions of the fixed network are all features that can be handled by SDN.

Different topologies can be implemented for this use case, specifically:

- star (PMP) classical topology with the need to handle the multiple access at the aggregation node;
- mesh (MPtMP) topology, with the need to handle optimal path computation to the aggregation node.

In both cases an SDN controller can be in charge of the related management taking also into account the status of the backhaul segment.

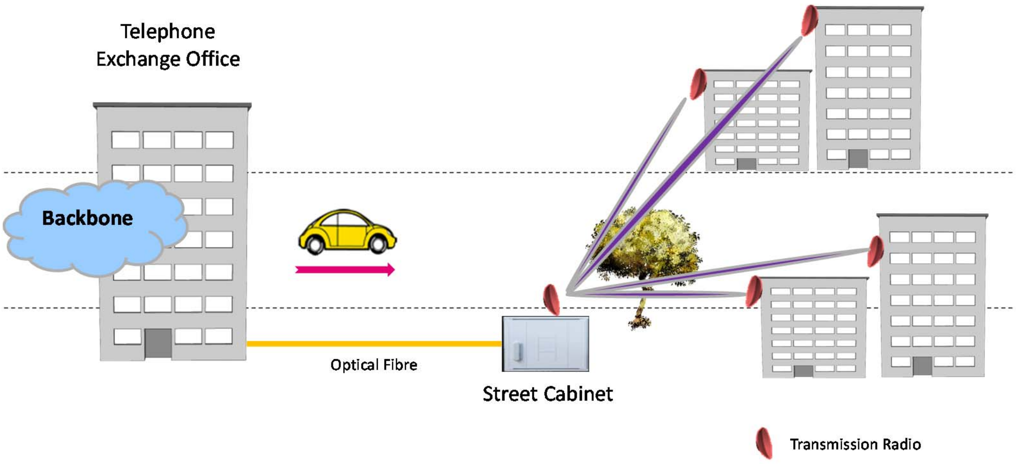

Figure 8: Wireless to the Home (WttH)

Value	• Last mile wireless connection provisioning • Joint management of both user-to-cabinet and cabinet-to-backbone connections
Specific needs to be addressed	• PMP shared access handling (statistical multiplexing) • MPtMP optimal path computation handling
Applicability	• FWA networks
Time scale of events	• Fast street level events: milliseconds • Street level events: seconds/minutes • Atmospheric events: minutes/tens of minutes • Topology changes: some events per year, hours
Reaction time of SDN	• Seconds or minutes
Specific contribution to/from SDN	• Centralize network intelligence, allowing e.g. learning of historical data like stable reflections, etc.
Potential issues/problems	• Network stability
Related/dependencies	• WttC. Self-backhaul

5.2.9 Fixed Broadband - Wireless to the Cabinet (WttC)

MW/mmW technology can be used to backhaul Fixed Access equipment; in this case, due to the dynamic nature of the radio channel, the flexible management offered by SDN becomes essential.

One advantage added by SDN to this network segment is the possibility to adapt the capacity of the radio link to the traffic requirements of the access segment in terms of throughput and QoS.

On the other side in case of temporary limitations of the radio channel (due for example to rain fading) proper traffic policing at both inputs of the link applied by SDN can prevent congestion.

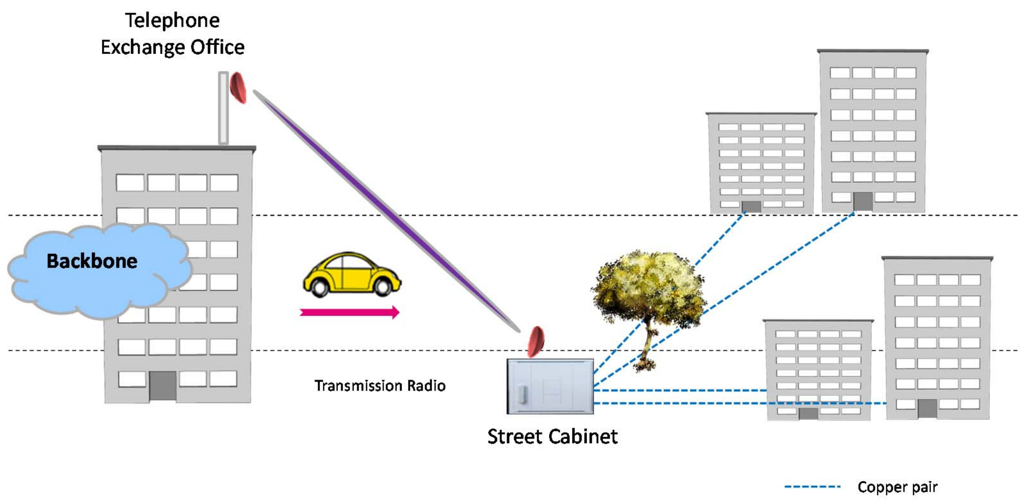

Figure 9: Wireless to the Cabinet (WttC)

Value	• Wireless backhaul of broadband fixed access • Joint management of both user-to-cabinet and cabinet-to-backbone connections • Optimize UL/DL capacity
Specific needs to be addressed	• Dynamic management of transient conditions (e.g. traffic load, atmospheric events, etc.)
Applicability	• Fixed access networks where the last mile is wired, but the connection to the CO cannot be implemented with a wired solution
Time scale of events	• Minutes or longer
Reaction time of SDN	• Minutes or longer
Specific contribution to/from SDN	• Real time adaptation to dynamic radio channel and/or variable traffic
Potential issues/problems	• None
Related/dependencies	• WttH. Self-backhaul

5.3 Radio link network segment in end-to-end view

5.3.1 Introduction

The end-to-end scope is the one with the highest potential to add value to the MW/mmW segment in an SDN approach due to the possibility to manage the network resources in a holistic way according to the service requirements, even if going towards a wider network range the relevance of the MW/mmW segment may become less evident.

The SDN paradigm itself makes full sense as long as it is applied to the network as a whole.

On the other side end-to-end use cases are the most demanding ones since they imply coordination and orchestration of very different parts of the network in terms of technology, layer, operator and vendor.

5.3.2 Bandwidth on demand

According to the traffic requested by the particular service, the end-to-end required bandwidth can be assigned throughout the network when and where needed.

A possible example is the delivery of a video and/or gaming content to a customer following his request.

The MW/mmW segment will be requested to be able to adapt its bandwidth according to the provided service, for example by activating/deactivating additional carriers in a radio link bonding connection, both in the same frequency band (carrier aggregation) and in case of multiband (MW link plus mmW link).

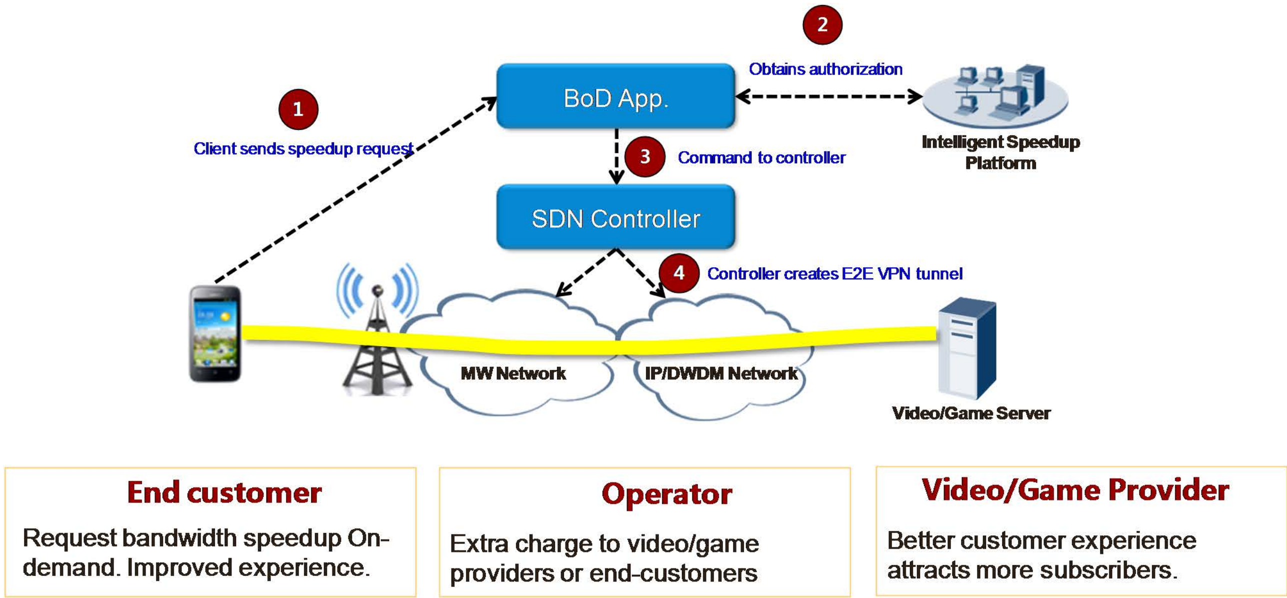

Figure 10: Bandwidth on demand

Value	• Enhanced customer QoE
Specific needs to be addressed	• Real time and adaptive service provisioning
Applicability	• Any network
Time scale of events	• From sub-second to permanent
Reaction time of SDN	• Strongly depends on the event/action time scale
Specific contribution to/from SDN	• Coordinated management across different domains end-to-end
Potential issues/problems	• Wide bandwidth and low latency to be guaranteed at the same time
Related/dependencies	• Multilayer optimization

5.3.3 Optimal traffic routing

This use case is an extension of the ones described at radio link level (see clause 5.1.3) and adjacent domains (see clause 5.2.5), with the highest possibilities of efficiency (from which the name 'optimal').

Each relevant traffic type/flow can be optimally routed over the available network resources based on the topology, traffic load and capacity over the entire network; since taking into account the network as a whole, at this level it is possible to achieve real optimization and not just dynamic adaptation as in case of just one or two network segments.

This use case concerns optimization over several domains: mmW, optical, IP, RAN, maximizing the E2E performance in terms of user experience.

In this use case, the traffic routing and QoS configuration may take a path that is not strictly optimal based on only one domain, e.g. the optimal BTS to reach a customer based on the RAN criteria may provide a worse quality than a BTS that has much better backhaul conditions (due to mmW, router or optical network congestion for example); nevertheless full network optimization is the target when considering end-to-end scope.

Value	• Reduced OPEX due to real-time network adaptation
Specific needs to be addressed	• Centralized congestion handling • Optimal network performance
Applicability	• Any network
Time scale of events	• From sub-second to permanent
Reaction time of SDN	• Strongly depends on the event/action time scale
Specific contribution to/from SDN	• Coordinated management across different domains end-to-end
Potential issues/problems	• Network stability
Related/dependencies	• Extension of dynamic traffic routing between adjacent network segments • End-to-end QoS

5.3.4 Network slicing

Telecommunications networks are currently based on a quite monolithic architecture that will not be "flexible and scalable enough to efficiently support a wider range of business needs when each one has its own specific set of performance, scalability and availability requirements" [i.4].

Network slicing concept is a proposed architectural solution in order to overcome these limits and SDN is the natural base on top of which flexibility and scalability can be built.

Network slicing is a logical instantiation of a physical network according to the requirements of a particular service. The idea is the selective activation of the network resources that are necessary for a specific service class, so to guarantee the fulfilment of the service requirements in a paradigm also known as Network as a Service (NaaS).

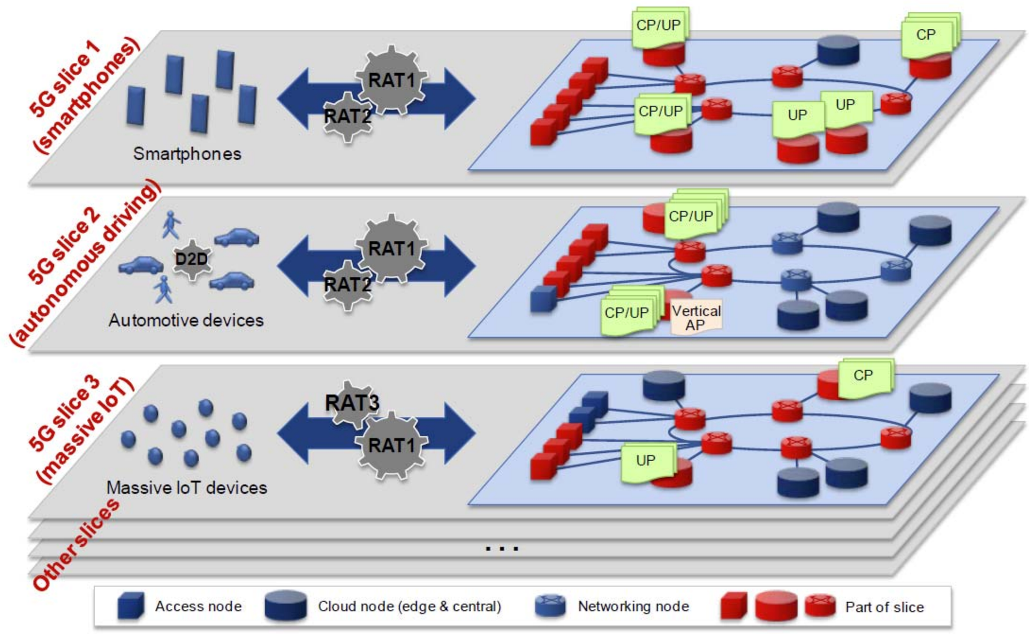

Figure 11: Network slicing concept

The slices can be network-wide or regional, permanent or temporary, and require policy adjustment based on the coexistence with other slices.

This is a fundamental enabler of 5G architecture, due to the very variable quality of requirements for the different verticals to be served.

A possible example related to MW/mmW segment is its partial/total activation/deactivation on the base of its available bandwidth (in case of a broadband service) or of its maximum delay (in case of a low latency service).

Another example, hereafter explained, can be related to Bands and Carrier Aggregation (BCA) feature, which can enable network slicing deployment in the wireless transport domain, assuring end-to-end optimization [i.5].

BCA is a way to combine individual characteristics of different frequency bands in order to obtain a single link with much more benefits. For instance it could be possible to combine over the same link a microwave frequency (generally enabling long link distance and high reliability) and a millimetre wave frequency (providing very low latency and high bandwidth).

Carrier aggregation allows combining the two channels over the air, providing eventually the better of the two in terms of performance. In fact the combined link can reach the longest distance, various steps of latency and reliability (from UH to L) due to the different logical sub-channels.

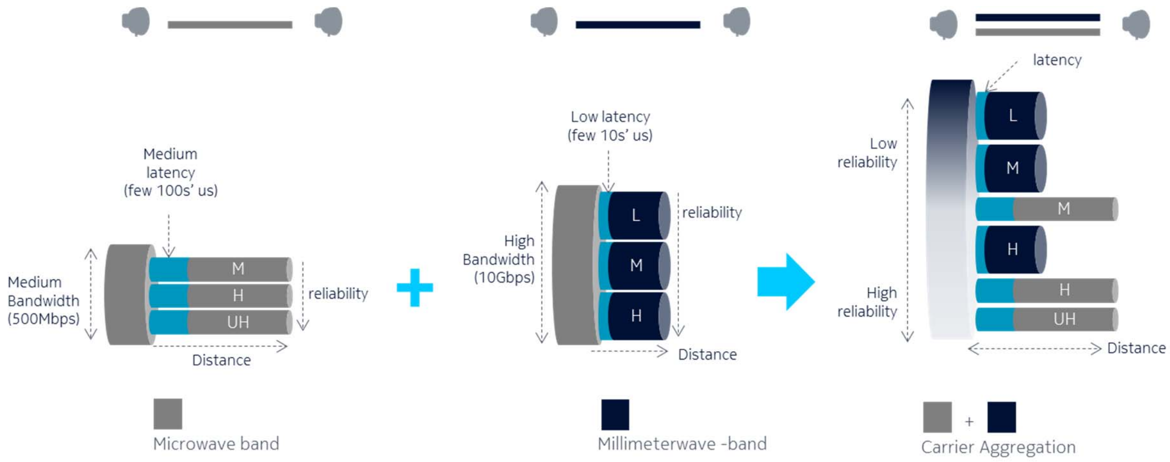

Figure 12: Bands and carrier aggregation

These logical sub-channels can be exploited in order to optimize the transport of the different services, with the support of an SDN controller which has full E2E knowledge of the network.

Assume that two different services (with different SLAs) need to be transported over the network, connecting the end user with a given application:

- Service A requiring high bandwidth and ultra-high reliability (e.g. assisted surgery in remote Health use case).
- Service B requiring low bandwidth and ultra-low latency (e.g. industrial coordinated robot control).

In this case, Service A can be mapped to a sub-channel which provides ultra-high reliability and Service B to a sub-channel providing ultra-low latency, as in figure 13:

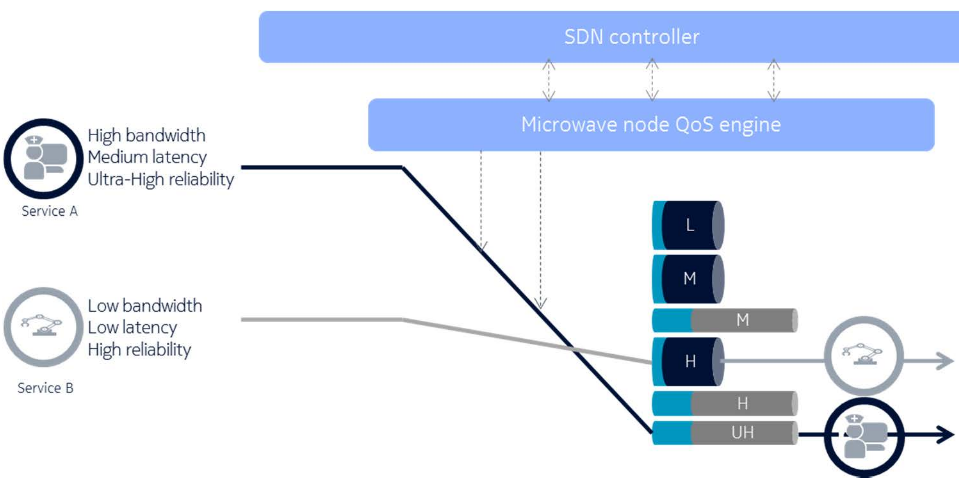

Figure 13: SDN handling of BCA

Once mapping is done, this radio link is able to transport every service, then this information will be transferred to higher layers which will know that the radio link can guarantee those SLAs (and will be able to apply this in a dynamic way). Such operation involves also QoS settings, therefore it could be related also to what mentioned in clause 5.3.5; moreover the SDN controller can also optimize the full E2E path through dynamic L3 VPN creation as described in clause 5.3.8.

A further enhancement in implementing network slicing with BCA is to consider the combination of the different bands as a "fat pipe" and managing it dynamically according to service needs at higher layers than just physical.

Value	• Secure business goals (existing and emerging use cases) • Optimize E2E conflicting service requirements • OPEX savings
Specific needs to be addressed	• Adaptivity of the network to the very different required services • Serving very different requirements with the same physical infrastructure • Fulfil targeted KPIs of emerging use cases (applying specific network configurations when needed)
Applicability	• Any network
Time scale of events	• Slice lifetime (expected at least hours/days or longer)
Reaction time of SDN	• Seconds/minutes
Specific contribution to/from SDN	• Flexibility, programmability and automation
Potential issues/problems	• Network stability, resource contention
Related/dependencies	• End-to-end QoS • VPN handling

5.3.5 End-to-end QoS

QoS in packet network is traditionally handled by means of two main approaches: Integrated Services (*intserv*) and Differentiated Services (*diffserv*), the former based on protocols for network resources reservation, the latter based on packet marking (at L2 or L3) and proper queuing strategies at the NEs. Both ways have advantages and drawbacks, the main limits being scalability for intserv and hop-by-hop handling for diffserv.

Managing the user experience requires sophisticated and adaptive management of QoS across the whole network, taking into consideration the specific characteristics of each technology/network segment and the time-varying network conditions. SDN is able to provide such end-to-end and adaptive handling of QoS.

Moreover since the peripheral parts of the network tend to be the most variable as regards technology, spectrum, topology, etc., and the most volatile as regards capacity, congestion, latency, etc., it is essential that a holistic approach to QoS be used to be able to effectively manage the actual user experience.

Value	• Dynamic and end-to-end QoS management
Specific needs to be addressed	• Optimization of backhaul resources allocation • Fulfil customer services in a dynamic fashion • Backhaul QoS optimization, namely no limit on lower priority services, in case more bandwidth is demanded at given time, while higher priority services will not be jeopardized at the same time
Applicability	• Any network
Time scale of events	• Service/slice lifetime (expected hours, days or longer)
Reaction time of SDN	• Seconds/minutes
Specific contribution to/from SDN	• Coordinated management across different domains end-to-end
Potential issues/problems	• Network stability
Related/dependencies	• Optimal traffic routing • Bandwidth on demand • Network slicing

5.3.6 End-to-end OAM

This use case is an extension of the one described at radio link level (see clause 5.1.5), with the highest possibilities of efficiency.

OAM functions are currently implemented by means of a complex set of proprietary systems. The biggest challenge is to coordinate them in order to manage the entire network (usually multi-technology and multi-vendor), streamline operation, reduce potential risk for human error and allow in the future the fast and efficient deployment of new end-to-end services.

Among the functions that can gain added value from an SDN holistic approach, two relevant ones are fault management and troubleshooting that can be effectively handled taking into account the full network connection end-to-end.

Value	• Reduce OPEX and CAPEX due to less complex NMS/OSS/BSS architecture • Less OPEX due to more efficient network management • Less OPEX due to less frequent and faster troubleshooting (more efficient collaboration across different technology teams) • Faster TTM (expedited services provisioning) • Increase customer satisfaction (quicker services provisioning, reduced time to resolve issues)
Specific needs to be addressed	• Holistic network management - allow E2E management information at all levels • Allow E2E management across entire infrastructure (all NEs) - Enable such functionality across multi-vendor and multi-technology boundaries • Enhanced Inventory management - guarantee that Operations have a correct and up-to-date picture of the existing network's structure and configuration • Better quality & quantity of alarms - root cause analysis considering entire network status • Intelligent Performance management with relevant KPIs • Increase operational efficiency and reduce potential for human error
Applicability	• Any network
Time scale of events	• Minutes or longer
Reaction time of SDN	• Minutes
Specific contribution to/from SDN	• Coordinated management across different domains end-to-end • Allow these functionalities to be implemented in truly vendor- and technology-independent fashion
Potential issues/problems	• Interaction with the NMS to be clarified • Level of automation, e.g. root-cause analysis algorithm and troubleshooting actions, SW upgrade, etc.
Related/dependencies	• Extension of OAM of MW/mmW networks at radio link level

5.3.7 Service chaining

Service chaining is the concatenation of successive functions that are required in order for a particular service to be delivered. An example is a firewall function, which is composed by network address translation, deep packet inspection and access control.

At present service chaining is implemented by means of specialized network devices connected in the required sequence and individually configured with proprietary interface, usually by means of command line interface.

Moreover all traffic in the network often goes through all service function devices even if only a subset of the functions is really relevant for each of the traffic flows.

By means of SDN a service chain can be provisioned and modified by a logically centralized controller which has an overall view of the network, so reducing the chance of wrong or inconsistent configuration and avoiding sending personnel to the different locations for manually programming the devices.

Different traffic flows can be directed on different service paths in so optimizing the use of network resources and the quality of service guaranteed to each type of flow; for example video delivery flows will require to go through different service functions than a big FTP flow and a different service path is to be provisioned to a web surfing request.

Value	• Lower OPEX due to centralized service chain configuration • Possibility to generate revenue from new applications developed by means of service chaining
Specific needs to be addressed	• Agile and fast service provisioning
Applicability	• Any network
Time scale of events	• Lifetime of service/slice
Reaction time of SDN	• Minutes
Specific contribution to/from SDN	• Coordinated management across different domains end-to-end
Potential issues/problems	• Network stability, resource contention
Related/dependencies	• End-to-end QoS

5.3.8 VPN handling

Current VPN implementations, both L2 and L3, do require lots of manual and static configurations to be performed on switches and routers; this implies quite long provisioning time and low flexibility to any possible change. Even MPLS based VPNs suffer the same limitations, being the time requested to setup a new connection up to the order of months.

Software defined VPN can give the following advantages with respect to the current VPN implementation:

- rapid site turn-up
- agile, policy-driven automated provisioning
- efficient security management
- enterprise self-administration
- the possibility for the operator to offer service trials

Value	• Agile and fast VPN provisioning • Lower OPEX due to centralized and automated management
Specific needs to be addressed	• Configure the VPN E2E across segment, technology, operational, regional and vendor boundaries
Applicability	• Any network
Time scale of events	• Lifetime of VPN (hours or longer)
Reaction time of SDN	• Minutes
Specific contribution to/from SDN	• Coordinated management across different domains end-to-end
Potential issues/problems	• Complexity, E2E consistency
Related/dependencies	• Network slicing • Security

5.3.9 Synchronization

Synchronization is a fundamental networking function and an end-to-end service that can be managed in an effective way by means of SDN paradigm. As service providers are preparing their networks in the first place for LTE-A Pro deployments and later to satisfy 5G access needs, the topic of synchronization has to be thoroughly considered and carefully designed in the transport network [i.6]. Considering that frequency synchronization is today the baseline that already exists in the mobile networks, the criticality of introducing phase/time synchronization is increasing due to several reasons:

- Mobile Base Stations TDD operation in unpaired access spectrum.
- New radio access techniques (e.g. Intra-site carrier aggregation, CoMP, etc.).
- New applications like M2M-type communications and IoT will increase the demand for accurate and/or reliable communication (e.g. industrial automation).

- New transport solutions and technologies may be needed to ensure challenging transmission needs of 5G.

Whilst GPS equipment could be installed at each mobile site location, in practice this is not everywhere the most straightforward implementation due to potential LOS issues with the satellites, which becomes more prevalent at small cell locations in urban canyon and/or its potential susceptibility to jamming. In such cases, synchronization needs to be transport-based and to this end ITU-T has published recommendations, so that transport networks are able to provide and support frequency and phase/time synchronization following a standardized logic. For example:

- PTP-FTS according to:
    - PRTC/T-GM according to G.8272/8272.1 [i.12] and [i.13];
    - T-BC/T-TSC according to G.8273.2 [i.14].
- PTP telecom profile according to G.8275.1 [i.8].
- Sync-E (Recommendation ITU-T G.8261/G.8262/G.8264) [i.9], [i.10] and [i.11].

With regard to the SDN concept, synchronization could be part of a transport SDN network architecture as an end-to-end service. Moreover, SDN can provide proper tools for managing synchronization. For instance, one possible approach is to foresee a synchronization application on top of the SDN controller, which is able to provide sync actions, either directly or in response to requests from the NEs based on the particular sync protocol supported, as described above, and/or on the particular sync type required (sync in phase/time, frequency). From an OAM point of view, the SDN controller can be requested to:

- Retrieve and display the sync parameters (frequency, phase/time) of each NE
- Configure the sync parameters of each NE (based on above response)
- Display the sync chain on a network map (end-to-end)

Furthermore, considering that an SDN controller will be capable of having an abstracted view of the end-to-end synchronization topology, this entity could be enriched with additional functions. Considering that multi-technology domains exist in today's networks, timely recovery of synchronization is a key topic not only from performance point of view, but from operational perspective, as well. For instance, an SDN controller could dictate a specific NE or a group of NEs to change to a new synchronization source (T-GM, T-BC) due to certain parameters related to clock quality (degradation), link status (failure) and so on. This could provide great relief to service providers and respective network topologies can be evolved towards a more efficient design.

SDN use case on synchronization based on Recommendation ITU-T G.8275.1 [i.8] is due to be demonstrated at the 4th ONF PoC in June 2017, with the following features:

- Each device along the synchronization path implements a PTP clock
- Two use cases defined: one is with outage of the MW link, the other one is with outage of the Master Clock reference to GM clock

Value	• Lower OPEX due to: • Automatic synchronisation (re-)configuration • Optimal end-to-end synchronisation recovery • Faster operations (OAM) in terms of end-to-end synchronisation service provision, monitoring and troubleshooting
Specific needs to be addressed	• Ensure network synchronization, e.g. for specific mobile broadband services, in a holistic approach • Minimise synchronisation planning across different technology domains
Applicability	• Any network
Time scale of events	• Seconds or longer
Reaction time of SDN	• Seconds (depending on holdover capabilities in the network)
Specific contribution to/from SDN	• Coordinated management of synchronisation service across different domains end-to-end • Synchronisation planning can be based on sophisticated policies controlled centrally • Exploiting the cross-domain and cross-technology potential of SDN
Potential issues/problems	• Network stability
Related/dependencies	• ONF PoC of June 2017

5.3.10 Security

In the 5G and Internet of Things trend, security issues will be of ever growing importance, due to the huge number and variety of connected devices. Security threats can arise at different levels:

- Sensor and devices - resources and computing capabilities of endpoints will most likely be limited.
- Networking devices - limited authentication procedures and encryption.
- Platform and applications - open protocols on one side, proprietary systems on the other can be weakness points for opposite reasons.

In this context, SDN can be a key enabler for security implementation at least in the following points [i.7]:

- Centralizing network security policy and configuration management.
- Automating network security remediation.
- Blocking malicious traffic from endpoints simultaneously allowing for expected normal traffic.
- Network policy auditing and detection and resolution of conflicts.
- Possibility to implement security as far as possible in the periphery of the network (edge computing), so to reduce the number of affected users and the extent of the network impacted in case of attacks or fraud.

Potential threats to wireless network security include confidentiality attacks (such as eavesdropping or unauthorized access), integrity attack (such as signal interference or creating a signal disruption), various types of Denial of Service (DoS) attacks on the data plane and hacking attacks on the management and control plane.

The main security issues with specific regard to mmW/MW domain are:

- The physical location of the equipment is not strictly controlled as it is for a data centre or a telecom cabinet (a backhaul NE can be over a roof or even on street furniture, a fixed broadband terminal is at customer premises and potentially at street level too).
- Radio waves can be intercepted, for example due to antenna pattern sidelobes.
- Physical access to management ports is relatively easy (Ethernet or even Wi-Fi control port).

The main security policies that can be implemented in mmW/MW domain are:

- Authentication procedures at both device level (radio to radio authentication on a PtP link) and user level.
- Encryption techniques at different protocol layers (L1 to L3 and over).

- Provisioning of a secure tunnel between devices by means of VPN.
- Unusual conditions detection and reporting.
- Flow conditioning (capacity throttling, QoS adjustments).

Value	• Centralized control with actuation at the edge • Automation improves fast response • Segregation of the affected part of the network in case of attack • Customer will receive high-quality & secure services
Specific needs to be addressed	• Ensure security for data transmission
Applicability	• Any network
Time scale of events	• Minutes or longer
Reaction time of SDN	• Seconds (or longer, depending on specific issue)
Specific contribution to/from SDN	• Coordinated management across different domains end-to-end
Potential issues/problems	• None
Related/dependencies	• VPN handling

6 Conclusions

SDN technology is widely considered a fundamental enabler for the implementation of 5G networks bringing the flexibility, scalability and adaptivity that are required in order to satisfy the huge diversity of service requirements and type of terminals foreseen in the Internet of Things.

A holistic and end-to-end view is intrinsic in the SDN paradigm, opening the possibility to provide services and to optimize the network in real time with significant CAPEX and OPEX savings for the network operators.

Moreover wide and fast development of new applications and services can be foreseen due to the abstracted and standardized view of the network resources that is exposed to the application developers, in a similar way to what already happened in the smartphone context with the introduction of a common operating system.

The MW and mmW network segment can take advantage from the SDN paradigm directly due to its own peculiarities (in particular the dynamic nature of the radio channel), but even more advantage will come to it from being integrated in a wider network which is able to adapt to traffic variations in real time.

All stakeholders in the information and communication technology arena will be able to share the benefits of the new networking approach based on cloud, SDN and NFV, from application developers to internet service providers, from telecom operators to content providers, from equipment manufacturers to components manufacturers, to arrive to the final users of the networks which will be machines and sensors and actuators and, finally, humans.

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