SON, the glue that attaches DOCSIS mobile backhaul to 5G

A Simple And Scalable Way For System Integration Of DOCSIS As A Backhaul

A Technical Paper prepared for SCTE•ISBE by

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Introduction

DOCSIS is an attractive option for mobile backhaul (see reference [1]). It has been shown in several Proof of Concept demos that 1588 timing can be passed reliably over the DOCSIS network and that using LLX (low latency backhaul, not to be confused with low latency DOCSIS) the latency over DOCSIS for mobile backhaul can be reduced.

This paper will address the next level of system integration challenges of using DOCSIS as a mobile backhaul. To illustrate the system integration issues, consider the following example:

A small cell is connected over a DOCSIS backhaul. The small cell carries a number of sessions. A UE (user equipment such as a mobile phone) attempts to start another session but the utilization of the DOCSIS mobile backhaul is already too high. There are a couple of recovery options. The new session can be rejected, or the new session can be diverted to a macro-cell, or more bandwidth can be added to the DOCSIS link via PCMM, or the call can be diverted to an adjacent small cell. This paper and presentation will explore how SON (Self Organizing Network) can be the glue between the DOCSIS system and the 5G eco-system that owns the policies that can help define and execute any of the choices mentioned above while keeping a good separation of the cable domain and mobile domain.

The cable environment will also push traditional SON to new scaling requirements because of the use of small cells (and therefor a larger number of eNB to manager) and the new spectrum that cable operators may use.

1. SON Overview

This paper is about a particular use case: having SON help with the capacity management of a DOCSIS backhaul link. Having said that its beneficial to understand the bigger picture of what SON is and what it does as staging for the backhaul discussion.

1.1. SON in 3G/4G/LTE

In order to reduce the operating expenditure (OPEX) associated with the management of large number of nodes from more than one vendor, the concept of the Self-Organizing Network (SON) was introduced in 3GPP Rel-8. Automation of some network planning, configuration and optimization processes via the use of SON functions help the network operator to reduce OPEX by reducing manual involvement in such tasks.

Numerous SON use cases were addressed in the 3GPP standards and implemented for 3G and 4G/LTE networks, including the case of combined 3G/4G/LTE deployments:

- Self-establishment of gNB, automatic network configuration (Plug and Play)
- Automatic Neighbor Relation (ANR)
- Load Balancing
- Inter-Cell Interference management
- Random Access Optimization
- Capacity and Coverage Optimization
- Automatic healing
- Mobility Robustness Optimization
- Energy Saving

These use cases are supported in a multi-vendor environment. The SON procedures and OAM interfaces are used avoid cost-intensive mediation between different vendor nodes and side effects due to different detailed solutions (e.g. different optimization algorithm leads to ping-pong effects and swinging phenomena).

1.2. 5G use case

5G networks are expected to be more complex than 4G networks, in several aspects:

- More complex RAN technology is used ("New Radio")
    - Scalable OFDM-based air interface
    - Flexible slot-based framework
    - Advanced channel coding
    - Massive MIMO and beamforming
    - mmWave Radio
    - Slicing support
- Multi-technology RAN
    - mmWave 5G requires underlaying 4G deployment for basic coverage
- Essentially more Base Stations
    - Small radius of the mmWave cells
- Diverse topologies of the networks and network fragments
    - Flexible "Service Based" Architecture definitions
- E2E optimization
    - Slice based with SLA targets
- Densification
    - Multi-layer of Macro and Small cells
    - Multi-technology (NSA, SA)
    - Multi-Bands (mmWave and Sub 6GHz)
    - Multi RAN architecture (Monolitic and disagregatted vRAN)

SON solutions will have to adapt to support these new requirements.

1.3. C-SON vs D-SON vs hybrid SON

There are three ways in which SON control can be implemented:

1. C-SON: With the centralized SON approach the eNB do not have any control and all decisions related to RF or load balancing are done through a central control plane.

2. D-SON: The D-SON approach allows eNB to communicate peer-to-peer and make autonomous decisions without a central control point

3. Hybrid SON: it is possible to combine both approaches, especially in multi-vendor environments where C-SON and D-SON based equipment needs to inter-operate.

1.4. The Future of SON

The SON function can span more than the radio access network. It can collect network performance data and send commands to the network functions with the purpose of improving network performance. The 3GPP TR 28.861 provided basic architecture for optimization

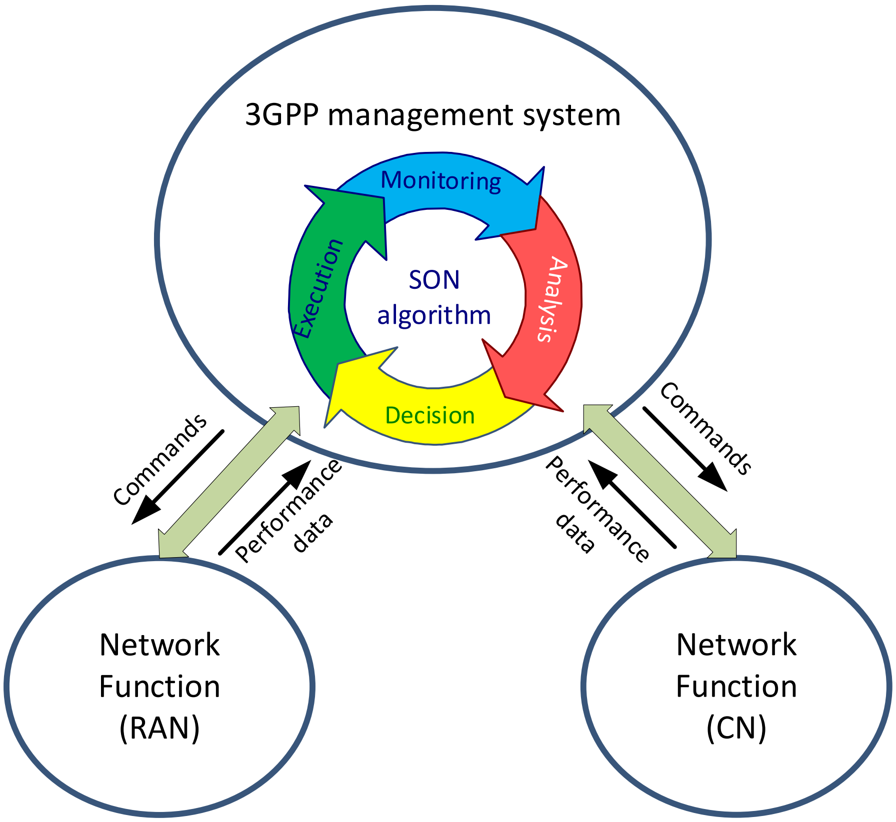

Figure 1 3GPP TR 28.861 C-SON View

The network operators clearly request E2E service assurance and a means to control it in the 5G networks. Implementation of this requires support of Multi-Domain Service Optimization (MDSO).

Aside from the classic RAN SON inputs, such as Network Element KPIs, performance measurements, Multi Domain Service Optimization (MDSO) is using Quality of Experience (QoE) indicators, and KQIs as an additional input. One example of E2E service specific quality metrics is video quality indicators.

MDSO is connected to multiple network domains, in addition to the RAN SON, for performance data collection and configuration commands to achieve the optimization targets. MDSO is set to monitor and optimize different SLAs for different services such as IoT, Video, and Voice in automate closed loop manner.

The MDSO allows E2E visibility of the mobile infrastructure and the quality of the content delivery. MDSO allows the content providers to optimize and automate the mobile network in order to meet the content customers service level agreements (SLAs).

Significant gains can be achieved by use of deep learning algorithms to identify and/or predict faults and/or performance degradation, isolate and remedy them. Machine Learning/Deep Learning (ML/DL) algorithms proved to be helpful in processing big data sources that accumulate the network performance metrics sampled at high frequency, and with breakdown to individual services (flows) rather than aggregated per RAN cell.

Figure 2 shows general network architecture of the MDSO in the 4G network. The MDSO deals with the following domains: NG-RAN, MBH, 5GC, Gi-LAN, IP services, NFV and Transport. The figure shows example of the video data flow crossing all network domains. Every domain may contain local controllers / optimizers. The MDSO Controller collects performance indicators from all domains and aggregates them into E2E QoS indicators with granularity of the sub-network or network slice or even individual UEs (QoS flows). Analysis of the E2E QoS indicators may trigger the MDSO Controller to certain actions performed on network functions in one or several domains.

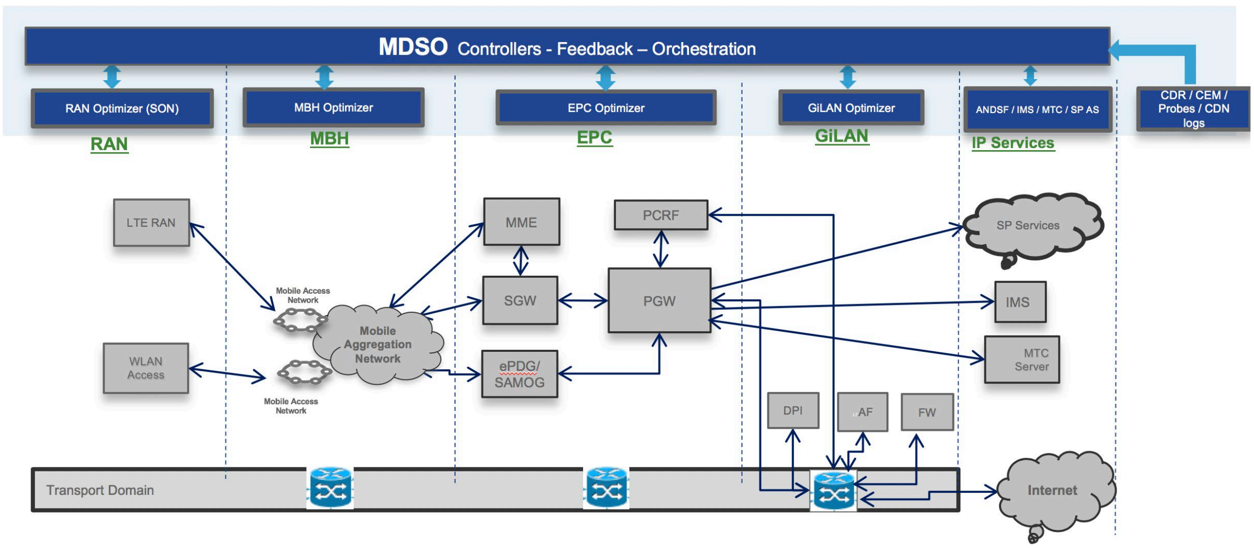

Figure 2 MDSO SON

As we will explore in this paper the specific domain that this future SON vision can help with in the backhaul segment in general and in particular the DOCSIS based backhaul (or fronthaul).

2. Deployment scenarios

DOCSIS as a backhaul can support several system deployments. In general, the DOCSIS as a backhaul is intended to be used with small cells. The following section outlines some of the options for deployment.

2.1. Indoor first (residential)

One can view the existing the exiting cable network as nothing but a "WiFi backhaul" because in most houses all devices are connected view WiFi and not directly to the cable modem. Similarly, a small cell can be deployed per-home and connect to in-home devices, and possibly server roaming devices as well. In this case the same coax drop that services the home is also used for mobile backhaul.

2.2. Outdoor First

In the outdoor first strategy the small cell is deployed over a coax drop in the outside plant that is dedicated for the small cell connectivity. The added value in this strategy is that the small cell can get power and a pedestal/pole to be mounted on from the cable plant in addition to the backhaul provided by DOCSIS.

There are commercial deployments of small cells over the cable plant even today. Some of them use the cable plant only for its real-estate and power, and the actual backhaul is carried over other technologies, but in some cases DOCSIS is used for the backhaul.

One common misconception is that the small cell can be directly connected to the remote phy or fiber node. This may or may not be the case because the location selected for an RPD or remote phy is not selected based on the ideal criteria for mobile but naturally based on the ideal location for the cable plant.

2.3. Hetrogenious Networks (HetNet)

Heterogeneous networks or "HetNet" refers to a mobile network that is comprised of different types of wireless technologies, including small cells and macro cells at different spectrum, as well as WiFi. In these types of networks SON is used to manage the complexity of all the various connectivity options.

2.4. Fronthaul vs backhaul (vRAN)

5G defines several split points that are possible between the RF head and the core as depicted in Figure 3:

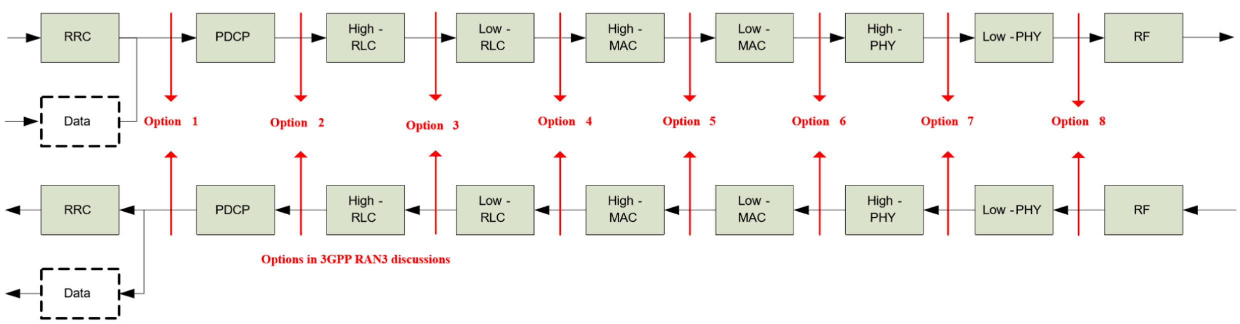

Figure 3 5G split options

When talking about backhaul we refer to split option 2. Traditionally the phy split is at option 7 and used by CEPI/eCPRI (see ref [5])). This split was relevant only for direct point to point fiber connections (basically to connect and antenna on the top of a cell tower down to the base station) because of the tight latency/jitter on this interface. More recently a new set of standards came out of the TIP (telecom infrastructure project) and ORAN (ref [6]) to support what is called an "imperfect fronthaul" and cablelabs has demonstrated how DOCSIS can be used to fronthaul mobile traffic (see reference [2]). Our discussion about SON as a way to manage backhaul is also relevant for fronthaul as well as the basic issues of link utilization and link quality are relevant to both (the fronthaul bandwidth used is not fixed and depends on the RF activity).

3. Problem statement

3.1. How to manage a limited capacity backhaul/fronthaul

In most networks the backhaul is not a bottleneck, with the exception of microwave based backhaul that can suffer degradation dues to weather conditions. However, DOCSIS is a shared media and reserving a fixed amount of bandwidth for mobile backhaul is not an efficient use of the DOCSIS resource.

The challenge is to account for backhaul availably and quality when making decisions on placement and load balancing in addition to the normal RF related criteria. As we will explore is section [4] SON is in a good position to provide a solution.

3.2. Residential scale

Any 5G deployment is going to increase the scale requirement from SON (or for that matter any solution that coordinates the RF resources across cells). The "indoor first" strategy (see ref [2.1]) in particular is stretching the scaling requirements due to the sheer number of small cells that we be deployed indoors.

4. Proposed solution

The following sections will outline how SON can act as a cross-domain orchestrator that accounts for the backhaul as well as the RF spectrum when choosing the optimal allocation or resources. Note that even though WiFi can be considered as one of the resources that can be used, it is out of scope for this paper in order to keep the discussion focused.

4.1. Solution architecture

4.1.1. PCMM framework

The PCMM architecture is described in ref [3]. For our discussion the key point about PCMM is that it's the glue between the SON system and the DOCCSIS system. Let's walk through an example when the SON system requests to increase the amount of bandwidth to the DOCSIS allocated to mobile backhaul to 200mbps. We will follow the numbered numbers in Figure 4.

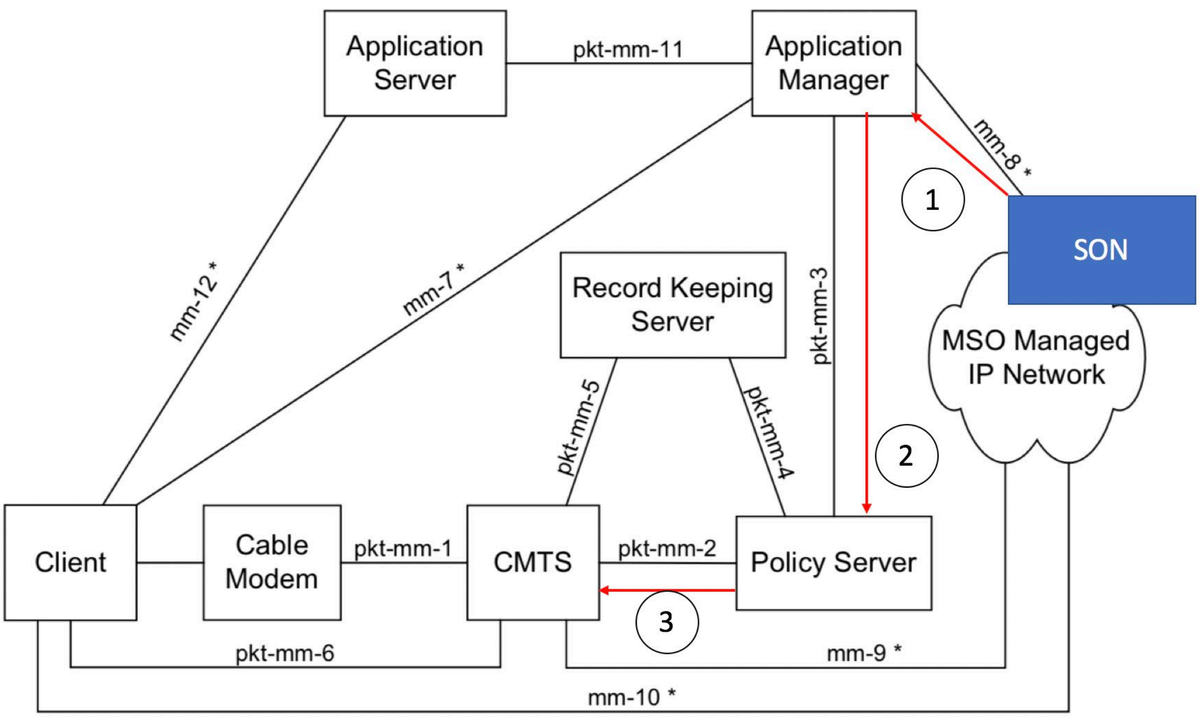

Figure 4 PCMM and SON integration

The figure above is a direct copy from the PCMM specifications (ref [3]), which contains a more detailed reference. For our example we will follow the exchange marked with numbers:

1. The SON system decides that the best way to resolve a particular issue is to take action on the backhaul side, in this case increase the backhaul bandwidth to 200Mbps. Using a pre-defined API, it signals to the application manager a request for 200Mbps with the specific ID of the cable modem that owns the backhaul interface. Alternatively, one can view the SON system itself as the “application manager”.
2. The application manager contacts the PCMM policy server which has a database of all the flows in the cable modem and which one/s of them is the backhaul flow.
3. Assuming that the policy server approved the request for additional bandwidth it will send a request through the COPS protocol to change the backhaul service flow to 200Mbps.

4.1.2. Telemetry data from the CMTS

The SON system needs to collect information from the DOCSIS system, example parameters that may be relevant are:

1. Utilization level of the DOCSIS service flow (e.g. if the DOCSIS service flow used for backhaul/fronahaul is 90% utilized some action might need to be takes)
2. Quality of the backhaul link (e.g. if there is a large number of uncorrectable errors on the DOCSIS flow used for backhaul/fronthaul then it calls for action as well)

4.1.3. SON/5G integration

SON can be integrated into 3G/4G/LTE frameworks as well, but for brevity we will outline only the 5G ecosystem integration.

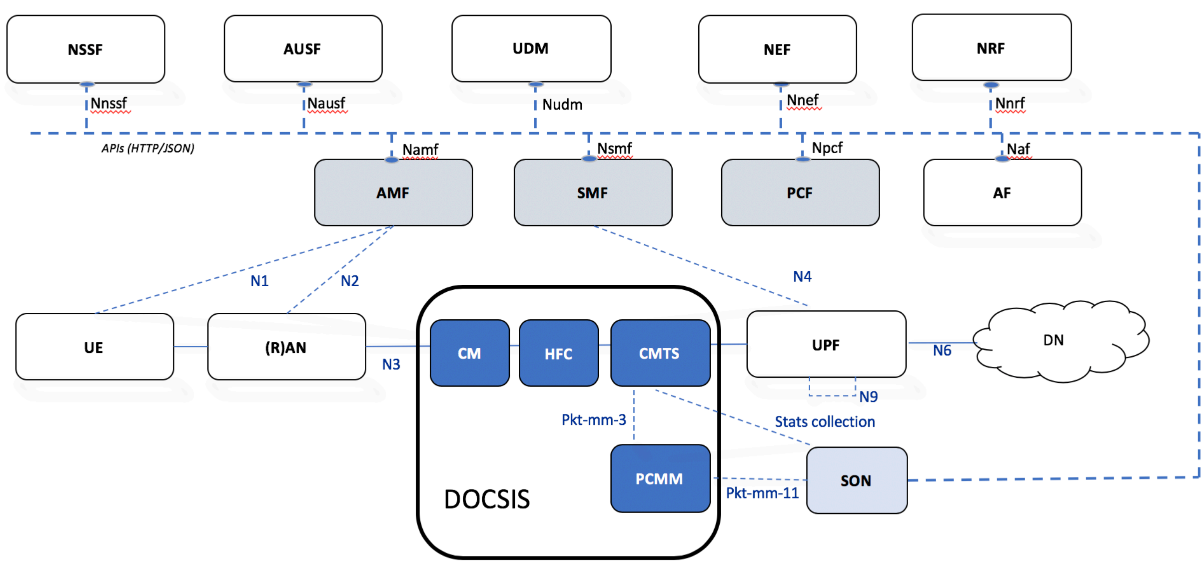

Figure 5 SON/5G integration

This basic architecture has been presented in reference [4] which has an overview of all the 5G components shown in Figure 5, in this paper we will focus on the use of SON to control the DOCSIS backhaul.

As can be seem in Figure 5 the cable plant can be viewed as part of the transport infrastructure (N3 interface). The 3GPP specifications does not provide much guidance on the transport and its assumed to be part of the service provider metro network. Furthermore, its assumed to be non-blocking, but as the 5G rates are increasing even this basic assumption has to be re-examined on any N3 interface.

While the exact control of N3 is not specified it is typically a fiber or ethernet network (with LTE or microwave backhauls in some cases) and is controlled as any switched/routed network, either by vendor proprietary systems, or MEF (metro ethernet forum) specified interfaces or SDN (software defined networking) systems. DOCSIS as a backhaul fits into this transport and while DOCSIS can be updated to support modern policy interfaces it already has the PCMM interfaces defined and tested and therefor the PCMM path is the easiest path for actual deployments. Note that for the SON solution we don't necessarily have to use a full PCMM ecosystem. They key is the COPS protocol (a very simple protocol of basically two message exchange) to communicate QoS requirements to the CMTS. Note that in a software application centric world the nature of the protocols and interfaces is secondary, and the key focus is on the application software and its business value.

4.1.4. Mitigation options

When the SON system detects that the backhaul is congested or compromised because of high error rates it can mitigate in different ways. Some examples may be:

- Load balance UEs to a different small cell
- Load balance UEs to a macrocell (possibly of a different provider)
- Add bandwidth to the DOCSIS link
- Throttle bandwidth from the UE (by applying a policy at the UE or eNB)
- Reject the UE

The choice between these options can be based on policy and machine learning.

4.2. Use Cases

The following are example use cases to demostrate how the SON system can help with the system level integration of DOCSIS backhaul/fronthaul.

4.2.1. 10 calls are active, adding a 11th, backhaul runs out of capacity

Voice is straightforward because it uses a fixed amount of bandwidth and admission control can be easy to calculate. If the CMTS runs an admission control protocol it can report the admission level which the SON system can query and if admission level gets too high the SON system can take a recovery option.

4.2.2. Data usage, utilization of backhaul is high

The SON system can query the utilization of the backhaul links and if they exceed a certain threshold being with one of the mitigation techniques until the utilization is reduced.

4.2.3. High bit-error rate on backhaul

The backhaul itself can be susceptible to errors. In the indoor case a loose connector can be enough to cause excessive errors on the DOCSIS link. If such a condition occurs traffic can be load balance to an adjunct small cell

4.2.4. Capacity off-load from macro cell

Small cells can be used to offload traffic from a macro cell, and also the other way around, a macro cell can be a backup for a group of small cells.

4.2.5. Dense residential small cell, cases where my UE is better served by the adjacent apartment small cell

In a dense deployment there might be no "the small cell in my apartment has priority for my devices" because there may be no private/public network (like with the wife public SSID). Because of that a small cell in apartment A might be best to serve a UE in apartment B.

4.2.6. vRAN use case

As mentioned in section 2.4 the discussion on backhaul is equally relevant to the fronthaul and the vRAN use case and a DOCSIS service flow that carries fronthaul traffic that gets congested or dropped needs to have the same remediation strategies as a backhaul flow.

4.2.7. SON/MDSO closed loop mitigation flow

Positive end user experience requires superior E2E Network performances at all the relevant domains (RAN, MBH and Packet Core). One of the main KPIs is the throughput achieved by the network. This throughput depends on both Radio and Transport dimensioning and status.

The SON MDSO mitigation flow presents in high level how SON/MDSO closed loop optimization platform collects information from DOCSIS, RAN (Macro and Small cells) and Packet Core.

4.2.7.1. SON/MDSO data collection & triggering

SON collects per-domain information which contains domain configuration (in case an action may be performed on this specific domain) and different KPIs (such as domain Load level, Throughput, Errors, Drops and more) which are required for meeting and maintaining the SON algorithm target function.

One evolution of SON is the user level awareness, which is obtained by collection of ULI (User Location Information) events from the AMF, and User throughput from UPF, SON can trigger not only based on Domain load/High utilization but also based on users SLA (e.g. minimum throughput).

Based on the information collected and a set of predefine thresholds SON can detecte degradation in user experience/SLA and/or overutilized domain (Cell or link) which triggers Root Cause Analysis (RCA).

4.2.7.2. Root Cause Analysis (RCA)

RCA is a SON internal process that based on ML algorithm that decides which mitigation action should be taken.

The ML decision is based on the event and domain trigger but also on the previous successful actions.

For example, in some cased DOCSIS over-utilization can be resolved by offloading the traffic form small cell to another small cell, but in other cases the best action could be to change in maximum allowed bit rate of user/users.

4.2.7.3. Mitigation action

The result of the RCA is recommended mitigation action, which can be one of the following example actions:

- Offload users between source loaded Small cell to one or several small cells
- Offload users between source loaded Small cell to one or several Macro cells
- Change DOCSIS allocated BW
- Change maximum allowed BW to one or group of users

4.2.7.4. SON/MDSO Feedback

The system needs to validate that the mitigation action did help with resolving the issue it was set to resolve. The main target of the feedback loop is to validate the cause of trigger was resolved, but it also check whether the action from some reason caused degradation. In case of performance degradation, the SON will revert the mitigation action. The results of the mitigation action can also be used for machine learning to have the system automitcally leared which mitigation stragey had the most positive impact on the system KPIs.

4.2.7.1. SON/MDSO closed loop flow exmple

The diagram in Figure 6 presents SON/MDSO closed loop optimization cycle, where Cell A was detected as a Cell with an over-loaded DOCSIS backhaul aand different set of actions can be selected. Please note, to resolve the issue not all actions will be performed but the ones with the higher probability to succeed.

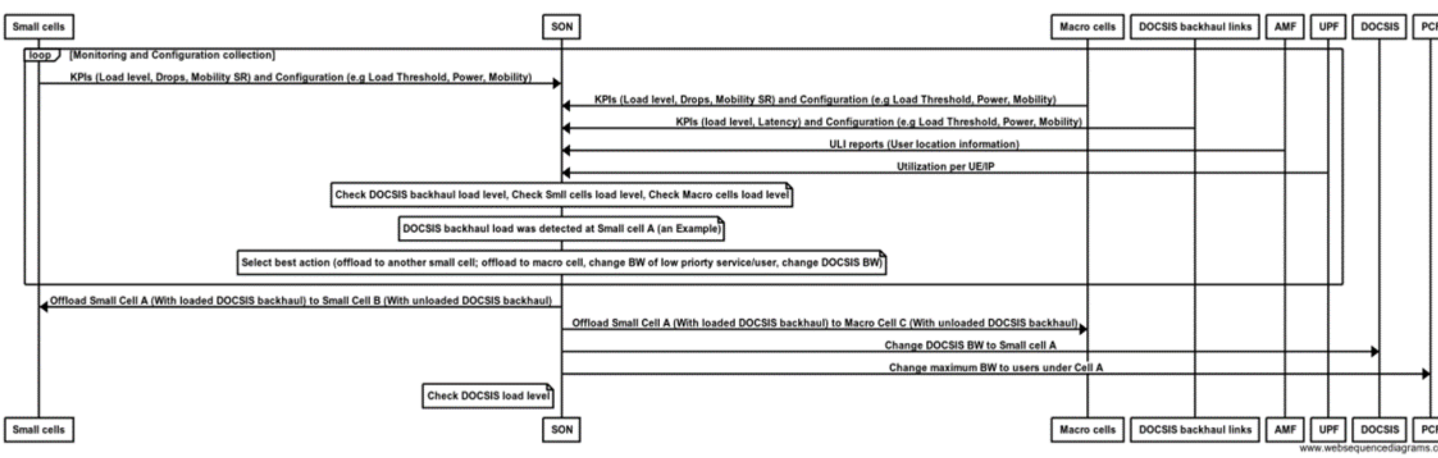

Figure 6 SON/MDSO mitigation flow

Figure 6 depictes how SON can act as a centlitzed controller, collectioing KPIs and reports, checking them against pre-defined polices and taking an action, which in our case is baseback related.

Conclusion

SON is evolving to become a multi-domain controller that can ensure a superior end-to-end application experience. The backhaul/fronthaul is one of the most critical and costly resources of a mobile network and efficient use of it helps both the application experience and cost reduction.

In this paper we have outlined how a SON system can integrate with DOCSIS in a simple way that does not require any major changed to either systems, only development of a few new APIs for monitoring as well as re-using existing APIs that were already defined by PCMM.

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