Software-defined Open Architecture for Front- and Backhaul in 5G Mobile Networks[1]

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ABSTRACT
New software-defined open network concepts are proposed in this paper to enable an efficient implementation of front- and backhaul solutions for future 5G mobile networks. Main requirements for 5G front- and backhaul are derived and then related to the open network architecture enabling multiple operators to share the same physical infrastructure. The value of software-defined networking (SDN) is particularly outlined therefore. For the use of SDN in the fronthaul, CPRI over Ethernet (CoE) is proposed as a new transport protocol. In the backhaul, distributed security can be implemented using SDN where direct links are confined inside the access domain, as opposed to the current centralized security solution including also the transport domain. In this way, low latency can be realized e.g. for machine-type communications. As the benefits for fixed-mobile convergence are evident, SDN should be enabled increasingly in the access domain.

Keywords: software-defined networks, mobile front- and backhaul, open access, CPRI over Ethernet, low latency, distributed security

1. INTRODUCTION

Concepts for the fifth generation (5G) of mobile networks are currently discussed both in industry and academia. From the data traffic evolution over the last years, high demands are expected. It is assumed that around 2020, a new generation of mobile networks will be deployed. Recent research has identified major challenges such as a massive growth in the number of connected devices and traffic, a wider and more diverse set of requirements and characteristics, starting from low latency and low rate for control messages between devices to multi-gigabits per second for interactive multimedia [1]. Researchers currently investigate how to serve 10 to 100 times more devices, deliver 1.000 times the traffic, and reduce the latency by a factor of 5 compared to 3GPP Long Term Evolution (LTE). In focus are promising techniques to meet these challenges at reasonable costs.

Besides new radio concepts, it is clear that the high requirements of 5G have significant impact on the network behind the radio. It is commonly assumed that both, the mobile and the fixed access networks will be optimized jointly to meet these high demands. Future access networks integrate a multiplicity of fixed and wireless technologies (e.g. fiber, cable, DSL, micro- and mm-wave, free-space optics) by using Ethernet and IP protocols as integration platform. Moreover, by using these protocols, it is possible by means of virtualization that multiple operators share a common physical infrastructure. The support of multi-vendor technology and use of the network by multiple operators becomes possible in so-called open networks.

In this paper following, several ideas are discussed how to use open networks efficiently for 5G service delivery. The objective is to identify promising research topics and to stimulate discussion among wireless and fixed network experts. The paper is organized as follows. In Section 2, new radio technologies envisioned for 5G are reviewed. The corresponding front- and backhaul requirements are outlined in Section 3. The software-defined network and its use to implement the open network architecture are described in Section 4. Promising enablers like CPRI over Ethernet and distributed security are discussed in Section 5.

2. 5G MOBILE RADIO

Following the exponentially increasing demand for high-speed mobile data, recent network evolution is directed to rapidly adopt new radio technologies. These technologies are increasingly sophisticated because the radio spectrum is a scarce resource and it has to be reused as often as possible for concurrent mobile communication.

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This is referred to as frequency reuse, which is limited by interference between the concurrent links. Advanced interference management schemes for 5G are outlined in [2].

Inside each radio cell, spectral efficiency can be enhanced by increasing the number of antennas. This approach has led to new research towards “massive MIMO” antenna arrays recently. The idea is to multiplex more data streams and to avoid interference into adjacent cells by using narrow beams. Transmission is further localized by placing small cells in the macro-cell network, where the user density is high. It is also intuitive that more localized transmission leads to increased energy efficiency. While 4G assigns different frequencies to small and macro cells to avoid mutual interference, 5G will reuse the spectrum and require appropriate interference management tools, accordingly. The most promising technique is coordinated multi-point (CoMP) where multiple base stations transmit and receive jointly. CoMP allows exploiting the interference so that the fundamental interference limitation of the cellular network due to the frequency reuse for concurrent links is removed. CoMP can be implemented equivalently in a centralized or distributed manner. Both approaches have been implemented and tested in the framework of LTE [3].

A large fraction of the increased data rates in 5G networks is attributed to more and more efficient spectrum use. More spectrum, e.g. at higher frequencies, scales the data rate of the existing technology. In contrast, infrastructure and spectrum sharing between mobile operators uses the spectrum more efficiently. But it needs additional support in the network. Nowadays, multiple mobile operators cover the same area using their own redundant infrastructures. By transmitting also from other operator’s sites, both the network density and hence the capacity can be increased without adding new sites. Moreover, the spectrum is not homogeneously exploited by each operator. Spectrum sharing allows statistical multiplexing between multiple operators already on the air. As multi-operator support is important, an open network approach is considered relevant for 5G.

3. FRONT- AND BACKHAUL REQUIREMENTS

The expected 1.000 time increase of the mobile data traffic in 5G compared to the roll-out of LTE Release 8 implies that the backhaul capacity can be expected to grow even more than that factor because modern radio technologies like CoMP need additional traffic between the base stations. Using a combination of several new technologies (small cells, CoMP, massive MIMO, carrier aggregation), radio capacity can be scaled to these anticipated values, see [2]. These high rates yield new requirements for front- and backhaul links.

In the fronthaul between the baseband unit (BBU) performing the radio signal processing and the remote antenna unit (RAU), small cells are not included. Massive MIMO is scaled up to 16 antennas per sector. With triple sectors and for 100 MHz bandwidth, a macro-site needs almost 100 Gbit/s if the digitized radio waveform transport in the fronthaul is already compressed to 8 bits resolution per I and Q baseband signal.

For same radio parameters, and 10 small cells per macro-cell, about 300 Gbit/s are needed in the backhaul to feed the base band processing from the mobile network side. A corresponding network model his shown in Fig. 1 left and the resulting radio and backhaul data rates are shown right [2].

Such high link rates are nowadays used in long-haul networks but not yet in the access. Although prices of 100G and beyond line cards are expected to fall due to the increasing penetration into the metro market, without further innovation, they will be higher than the price of a base station is allowed to be in 2020. Significant potential for cost reduction is expected from photonic components development, standard instead of proprietary protocols and digital signal processing. By following the current development for data centers, costs can be reduced.

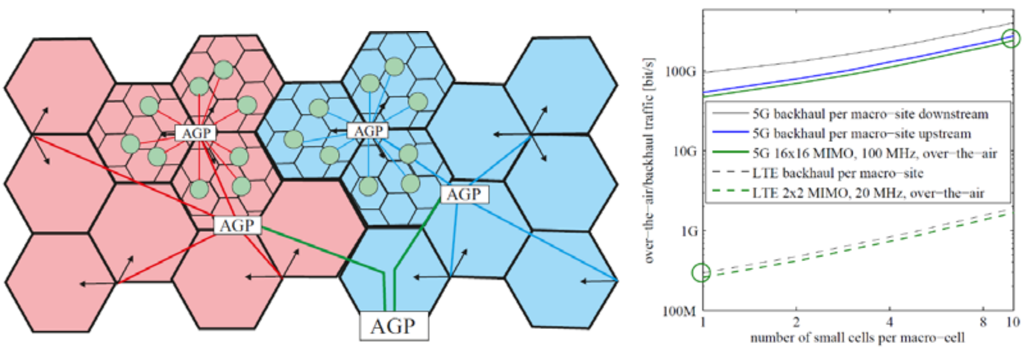

Figure 1. Left: Model of a 5G mobile network using triple-sectored macro-sites. At two sites, a massive MIMO array is deployed yielding subsectors. Small cells are also deployed and their traffic is aggregated at the macro-site. Backhaul is organized as a physical tree. Information exchange between cells is passed over direct logical links in the access network by using the next common aggregation point (AGP). Right: Over-the-air and

backhaul traffic versus the number of small cells per macro-cell. Circles indicate what radio parameters are needed to support 1.000 times the capacity compared to LTE Rel. 8.

A second requirement of 5G is to low latency. At the one hand, this comes from closed-loop mobile radio technologies like multiuser MIMO and CoMP that are sensitive to the feedback delay over the air and in front- and backhaul links. At the other hand, new mobile services like machine-type communications require low latency in general. A typical target value for 5G is 1 ms, as opposed to tens of ms in LTE [3]. Of course, there is some potential in the radio protocols. Note that a large reduction of latency can also be achieved in the backhaul network by using the distributed security solution, see Section 5.

The third requirement is enhanced synchronization. New radio schemes need a precise frequency reference besides the radio frame clock. Massive indoor deployment in the future suggests that the clock reference should be provided over the network. Already for LTE Rel. 10, the network needs to relay the precise time protocol IEEE 1588 from higher to lower aggregation levels. The use of CPRI over Ethernet as suggested in Section 5 will require a new precise frequency protocol.

4. SOFTWARE-DEFINED OPEN NETWORK ARICHITECTURE FOR 5G

For the 5G radio access network (RAN), both centralized (C-RAN) and distributed architectures (D-RAN) are considered, see Fig. 2. In the C-RAN, the base-band processing is pooled at a central office. Digitized waveforms are transported over the fronthaul from the BBU to the remote antenna units (RAU). In the D-RAN configuration, each base station has its own BBU and there is information exchange among them over the backhaul. While the C-RAN concept is simpler and has advantages for deployment and maintenance, synchronization is more critical in general. The D-RAN concept has relaxed requirements, e.g. lower data rates.

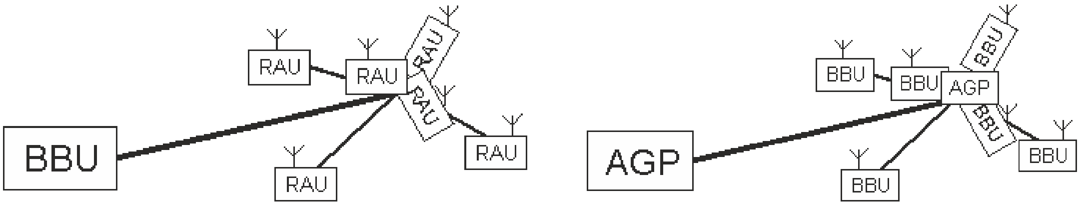

Figure 2. C-RAN (left) vs. D-RAN architecture (right).

The decision as to which architecture to use, depends on the fixed network owned by the operator. Incumbent operators are more interested in C-RAN because of their existing optical fibre infrastructure. Other operators may be more interested in D-RAN because part of the network infrastructure, in particular the access domain, has to be leased. Moreover, D-RAN may be relevant for spectrum sharing. Operators may use cooperative signal processing to eliminate the resulting interference.

The promising new idea is to support both architectures natively in 5G by means of SDN. In principle, any desired back- and fronthaul network (as well as networks for other functions) can be implemented on the same physical network by means of virtualization, given that network resources are sufficient. Multiple virtual networks can be operated in parallel, which enables the desired multi-vendor and multi-operator support in an open architecture. There are well-known MEF profiles by which e.g. C-RAN can be implemented using the E-tree profile while the E-LAN profile may be appropriate for D-RAN. This new idea provides unprecedented flexibility for the operators, however, the deployment of virtualized RANs needs some enablers described next.

5. ENABLERS

CPRI over Ethernet: In order to facilitate network sharing, besides common operation and maintenance (OAM) functions, a common transport format is needed. The use of an active remote node is recently proposed where Ethernet is used therefore [4]. However, the transport protocols of the common public radio interface (CPRI) used for baseband waveforms in the fronthaul and the Ethernet protocol used for data in the backhaul are incompatible. Although both use the same optical and electrical interfaces, drivers, chipsets and nearly the same clock speed, it is impossible to pass sampled waveforms through an Ethernet switch. Therefore, C-RAN needs a dedicated physical infrastructure where no flexibility is possible for sharing the network resources.

There are two ways out. One is wavelength-division multiplexing (WDM), i.e. the same fiber is used but different light colors for back- and fronthaul. A WDM bypass is currently discussed for fronthaul support in NG-GPON2. However, more flexibility of utilizing the network resources may be desired to maximize statistical multiplexing in the access domain, i.e. sharing should not be limited to optics and be enabled also in the electrical domain.

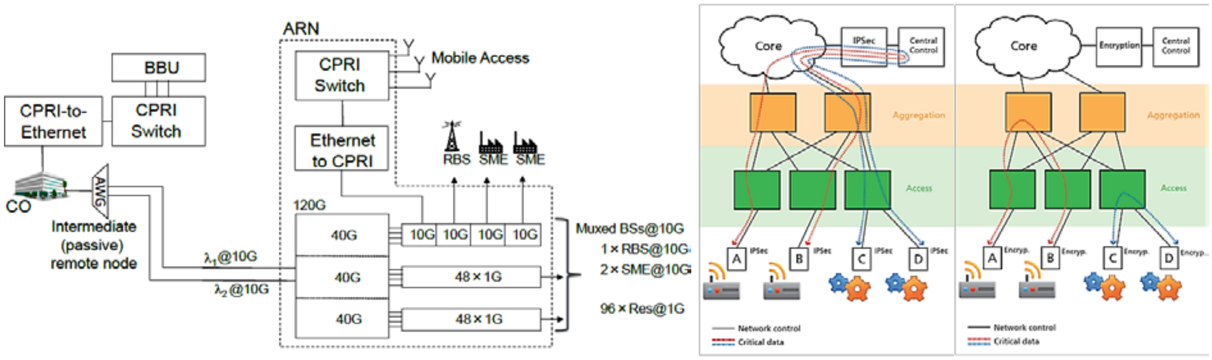

Figure 3. Enablers for SDN in 5G. left: Fixed-mobile convergence by using CPRI-over-Ethernet. Right: The centralized security architecture in 4G increases latency significantly. Using SDN, the direct link traffic can be routed over the nearest common aggregation points. Operator-specific e2e encryption enables reduced latency.

The Open Radio Interface (ORI) for the fronthaul recently unified only the proprietary signaling channels for operating the RAU while the transport protocol of CPRI is maintained. A possible way out for SDN in the fronthaul is shown in Fig. 3 left. In addition to serving a number of SME besides residential users and the backhaul of a radio base station (RBS), all connected to an active remote node (ARN), radio baseband samples are transported from a BBU at the central office (CO) to the RAU over the ARN. Obviously, conversion between CPRI and Ethernet protocols is needed therefore. Alternatively, baseband samples are directly transported over Ethernet. In this way, it becomes possible to use software-defined architectures also in the fronthaul.

Distributed security: Sharing the infrastructure is essential for 5G as it enables new business models currently investigated by the telecoms industry. E.g. an infrastructure provider can deploy the network, which is offered as a service to other (virtual) network operators and service/content providers. While open networks bring new market and revenue opportunities, at the same time, they create additional security concerns.

Consider the example illustrated in Fig. 3 right, where the backhaul traffic between the RBS and the centralized evolved packet core (EPC) is aggregated in two tiers, i.e., *access* and *aggregation network* [5]. If the operator owns the aggregation tier only, whereas the access domain is shared with other operators, the latter can be regarded as less secure. The critical handover function between the base stations, which is essential when measuring latency, is currently implemented so that the traffic is switched hard from one base station to the next over a central gateway. Remaining user data is copied over X2 to the target base station. Because this data is subject to privacy constraints, in particular if the access infrastructure is shared, mobile operators currently implement a centralized security architecture on X2 using an IPSec tunnel from each base station to the EPC, which can be located hundreds of kilometers away. However, the next base station may be much closer.

Latency in the mobile backhaul can be significantly reduced by passing data over the nearest common aggregation level (Fig. 3, right). In an open network, operators can be assigned virtual sub-networks operated independently and private. Operator-specific encryption can be used within these sub-networks. Distributed security is considered safer in general because the shared data is not accessible by other operators and at higher aggregation levels. Besides latency, the network load is also reduced in this way.

6. CONCLUSION

In this paper, the idea of a software-defined radio access network (RAN) has been proposed for 5G front- and backhaul. Requirements for the network were derived from the mobile radio side. It was argued that a software-defined RAN provides the required flexibility to support different architectures, such as C- and D-RAN by using the same physical network. However, a common transport format is needed therefore. Moreover, the idea of network sharing requires distributed security solutions enabled within sub-networks formed by SDN. Some challenges were identified already and will be discussed at the conference.

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