Data Plane and Control Architectures for 5G Transport Networks

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Abstract Next generation 5G mobile system will support the vision of connecting all devices that benefit from a connection. Transport networks need to support the required capacity, latency and flexibility. This paper outlines how 5G transport networks will address these requirements.

Introduction

The next generation mobile network, 5G, is expected to be introduced around 2020. With 3G and 4G, mobile traffic shifted from traditional telephony services to data, and with the evolution to 5G[1-3], it is expected that everything that benefits from a connection will be connected. We will see a massive growth in both traffic and the number of connected devices. As a consequence, there will be a range of devices supporting both user-services and machine-type communications. The network therefore needs to support requirements from very different services including e.g. sensor networks, industrial applications, media services, and evolved mobile broadband. Along with this evolution the traffic rates continue to increase and there is an increased focus on low latency for specific applications. At the same time, these services need to be provided in a cost-effective manner.

To address these challenges, densification of macro cells, and new small cells are used on the mobile side. To provide transport connectivity, re-use of infrastructure is important. Several research projects have investigated converged infrastructure[4] supporting both traditional residential and business access services as well as IP backhaul and CPRI-based fronthaul[5-6]. Extending the use of (D)WDM technologies provide the needed capacity, while interworking with IP is important to provide end-to-end control as well as efficient use of fiber infrastructure.

Another important area is the control system providing services in a flexible and programmable way. This goes across different technology domains, connecting end-point devices to the service functions. Increasingly, these service functions are deployed in a cloud environment, and can be centralized or distributed depending on service requirements. Coordination is needed across the different domains of radio, transport and cloud. To this end, we adopt an architecture based on software defined networking[7] (SDN). This makes the network programmable through software by control applications and services. Several efforts are underway, both in standardization and research to enable a fully programmable network[7-8]. An orchestrator allows programming across several network regions and technology domains.

The focus of 5G transport is how these concepts will provide support needed for next generation mobile networks. Requirements from emerging 5G radio technology and related use cases are identified and put in the transport network context, both from a data plane and a control plane perspective.

Services & 5G mobile system evolution to 5G

The 5G radio solution is expected to comprise of new Radio Access Technologies (RATs) and evolution of existing RATs exploiting existing spectrum as well as new spectrum (e.g. sub-6 GHz, mm-wave RAT)[2]. Both wider spectrum and technologies such as beam-forming and massive multiple-input and multiple-output (MIMO)[3] will be put in place, resulting in peak rates up to 10Gbps. As a consequence, transport networks will need to support higher peak rates at the cells sites. These new traffic requirements are driven by evolved and new services: (1) Media – the majority of traffic already in today's network is video, which drives the average traffic and system capacity; (2) Critical Machine-type communications (MTC) – applications with high requirements on availability, bandwidth, and latency, e.g. industrial applications and intelligent transportation systems; (3) Massive MTC – devices and appliances which are deployed in very large numbers, but where each individual unit has lower requirements on e.g. bandwidth and reliability, e.g. sensor networks; (4) Evolved mobile broadband supporting higher peak rates and overall capacity.

To support these new services and the increasing traffic, we see both a densification of traditional macro networks and new small cell deployments. In addition, different deployment options, e.g. integrated radio base station, centralized baseband, radio-over-copper solutions, will be utilized for different scenarios. In terms of supporting 5G radio, radio coordination capabilities for interference management are important. This requires either common baseband processing or low latency lateral connections between participating elements in order to support different flavors of CoMP (coordinated multi-point transmission). The radio coordination capabilities are inherently tied to the RAN deployment architecture (e.g. centralized or distributed baseband) and the capabilities of the transport architecture to provide required connectivity parameters. The RAN deployment architecture determines what type of mobile signals needs to be transported, e.g. packet, CPRI (Common Public Radio Interface), or low latency lateral connections for CoMP. Available transport capabilities and infrastructure may in turn constrict possible RAN deployment alternatives and radio interference coordination opportunities. For this reason, transport plays an important role in how 5G radio access and the Networked Society will be realized.

Data plane & deployment architectures

Mobile traffic is growing rapidly, but fixed traffic is still expected to dominate in the 2020 timeframe. To provide the needed connectivity to a densified macro network, and small cell deployments, re-use of existing infrastructure as well as sharing this infrastructure with traditional fixed services is important. There is a trend towards fiber to cell sites, although local conditions sometimes makes alternative solutions attractive, such as wireless links, self-backhauling and free-space opto.

In backhaul, IP is used from the antenna site. A site router or a direct link connects the base station to an IP-based transport network. The centralization of baseband equipment and use of CPRI to a remote radio unit provides coordination gains as indicated above, but also lower operational costs, by a reduced number of access sites. This comes at the cost of higher bandwidths in the transport. Extending the use of (D)WDM technologies closer to access enables more efficient use of fiber infrastructure, and lower power consumption. But even today, cost is limiting factor. Advances in integrated optics are important to provide more advanced functionality in a cost-effective way.

Fig. 1 illustrates the outcome of a dimensioning analysis of mobile traffic for a future (2020) dense urban network scenario. For simplicity we assume a fairly aggressive scenario with 100s of small cell sites per Macro and 1000s of Macros per Service Edge. More realistic near-term scenarios with e.g. 10s of small cells per Macro and 100s of Macros per Service Edge can be interpreted from the graphs as well. Fig. 1 shows capacity requirements of both links and intermediate nodes in different segments of the network. In the access region the red curve is split into several paths as dimensioning for macros and small cells is based on peak cell rate rather than average rate. For small cells we indicated a peak rate range between 0.3-3Gbps. The upper value could be achieved by utilizing wider spectrum and multiple MIMO layers. In the metro aggregation, the capacity curve scales with average traffic. Here, the red region indicates a range of different traffic densities. Assuming the access node covers an area of 5km^2, the indicated range is for traffic densities between 6-60Gbps/km^2. This is fairly high compared to dense urban traffic densities in EARTH[10] (<0.3Gbps/ km^2) but low compared city center traffic densities in METIS[1] (700Gbps/km^2).

For a centralized baseband deployment, the CPRI interface requires an order of magnitude increased capacity compared to backhaul. As an example, a three sector site with 100MHz bandwidth and 8x8 MIMO generates 118Gbps of IQ data (excluding CPRI overhead). Fig. 1 also indicates the required IQ transport capacity corresponding to the indicated small cell peak rate range. Capacity grows linearly with number of served cells as there is no statistical

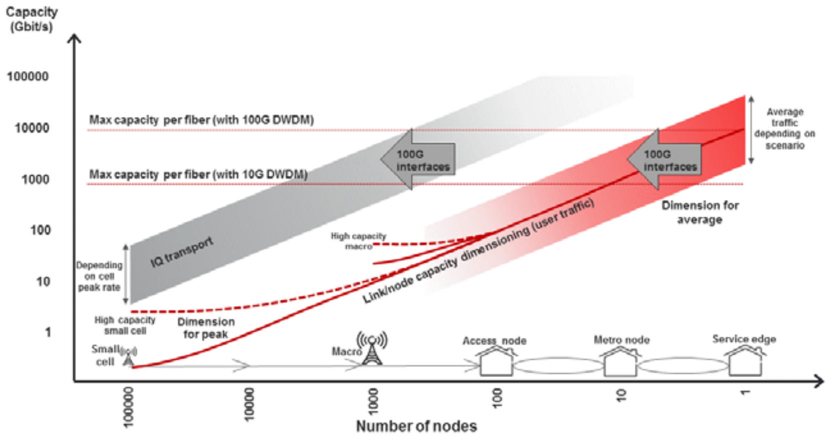

Fig. 1: *Schematic* illustration of capacity requirements in different network segments both considering user traffic and IQ transport (e.g. CPRI).

multiplexing gain in IQ transport. Fronthaul architectures and in particular combined with 5G radio technologies push the need for 100G interfaces even further out in the access networks. Especially for the case of massive MIMO solutions investigated in 5G, bandwidth for CPRI are quite high and probably not feasible from a transport perspective.

Control architecture

There is a wide range of services and requirements that the 5G networks will have to support, including sharing of the network for different purposes. Therefore, flexibility and programmability are important requirements for network control. We adopt an architecture based on SDN for this purpose. In an SDN-controlled network, a logically centralized controller provides an application-programming interface (API), which exposes networking infrastructure capabilities to higher layer control applications and services, and enables them to dynamically program network resources. The impact of such an API goes beyond traditional network control, since this allows deployment of applications on top of the infrastructure to automatically optimize across heterogeneous domains and quickly instantiate new end-to-end services.

Fig. 2 shows the simplified view of how the different domains of radio, transport, and cloud are brought together by an orchestration layer. Through the orchestration layer, different applications and services interface towards the underlying infrastructure. There are two sides of this: exposing capabilities and topology from the infrastructure, and providing programmable control of available resources. In exposing the infrastructure, different levels of detail can be provided depending on the requirements from services. For some services topology and delays are important to optimize performance, whereas other services only require connectivity between end-points. Different models have been investigated to balance such requirements. As multiple applications will be interfacing to one orchestrator, separation of control through slicing or virtualization is a key feature. Different applications/services will interface through the programmable API to control its allocated resources to enable flexible control, without impacting parallel services. The following main drivers for flexibility are identified:

- Rapid and dynamic service provisioning
- Optimizing resource utilization
- Rapid scale-out of service capacity
- Automation of network and services

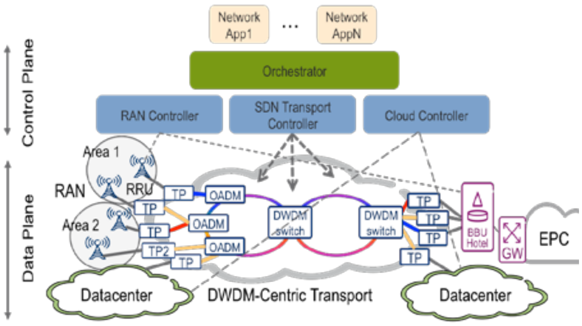

Fig. 2: Architecture of the multi-domain multi-service testbed with a hierarchical SDN control plane,

There are several scenarios where flexibility would be beneficial. Joint orchestration between radio, cloud & transport was demonstrated[11] to show how varying traffic demands can be utilized to enable infrastructure sharing between two different clients – a CPRI-based RAN, and datacenter bulk transfer.

Conclusions

5G transport needs to support requirements from new radio technology and deployment models, as well as providing exposure capabilities and programmability for a wide variety of services. Performance requirements will be quite stringent for some services, in terms of bandwidth, latency and reliability. An SDN-based approach is adopted to enable flexible control.

Acknowledgements

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