Research topics and initial results for the fifth generation (5G) mobile network

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Abstract— **The plethora of wireless devices resulting in a humongous data usage has already pushed the current mobile networks to their limit. Therefore the research and development of the next generation mobile network must take place now. In this regard a mobile network operator has a pivotal role in understanding the required performance of the coming fifth generation network, and also influencing its final design. This paper presents some network research topics seen from an operator's point of view. It provides an overview of some recent results within the following areas: network architecture utilizing network function virtualization and software defined networks, performance of deploying self-organized network functions, spectrum sharing, inter-cell interference reduction methods, and backhaul with gigabit radio links.**

Index Terms—**mobile network, network architecture, network performance**

I. Introduction

In the last decades the landscape of digital mobile telephony has changed from nice-to-have to must-have. People not only feel undressed without, but it penetrates more and more of our daily lives and will continue to do so in the future. In this scenario a breakdown of the mobile network, even for a short period of time, results in big difficulty for the whole society.

The development of new generations of the system is coming quickly; now the fourth generation (4G) is rolled out in many regions of the world and researchers are already busy defining and figuring out what the next generation, the fifth (5G), might be. It will not (at least not solely) be a static upscaling of 4G, but include brand new properties like dynamic resource scaling according to needs, personalization, net "follows you", service awareness, and automatic optimization. 5G may evolve from quite different vendor structures than of today. This may result in more vendors, finer granularity of vendor roles, extensive collaboration, new ecosystems, and common test beds.

This paper presents some views on 5G research topics as seen and worked at from an operator's viewpoint. It includes an overview of some of the recent results that have been achieved.

The paper is organized as follows: Section II addresses some basic information on new mobile generations. Section III gives a brief discussion of service aspects. Section IV deals with new research that is needed, in particular focusing on topics addressed by Telenor. Finally a few words about technology push is given in Section V, before the concluding remarks in Section VI.

II. New generation mobile network

Mobile communication growth is one of the most remarkable trends in telecommunication history. Although commercial wireless services were launched in 1946 [1], it was with the cellular coverage concepts and digital solutions the broad public started to use the services [2]. The GSM system was first launched in 1991 and paved the way for an incredible change of peoples' everyday life. Today, together with the Internet in the form of World Wide Web and fast information technology development of hardware and networks, it is difficult to see the future society without an advanced mobile system.

A dramatic increase in data traffic over the mobile networks is already taking place and predicted to continue in coming years. The average mobile data growth will be 47 % [3] to 61 % [4] on average in the period 2013-2018. Sometimes this type of reports has argued for a yearly doubling. Of course it depends on the starting point; starting from the very low volumes the increase rate may be significant.

So, either way a number of predictions indicate heavy mobile data growth for the coming years. This is due to a number of factors, such as, increasing number of users in total, increase of heavy data consumers, such as smart phones and tablets, and the growth of numerous other devices used in machine-to-machine communication. The explosive growth of mobile data traffic severely challenges network operators and hence is a major reason to continuously search for new technology that can deliver the wanted and demanding services with the often limited available network resources.

The next generation mobile, the fifth generation (5G), is expected to be commercially launched around 2020, as indicated in Fig. 1.

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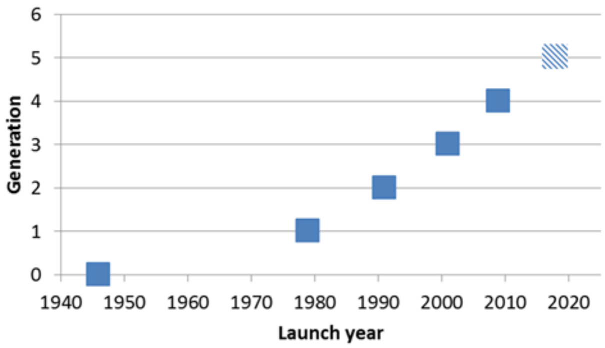

Fig. 1. Commercial launch year for new mobile network technology generations with an indication of 5G around 2020

The illustration in Fig. 1 shows the commercial launch year of the various mobile network generations [1][5][6] of public services. With respect to the estimated launch time of 5G it might be of interest to note that technology Long Term Evolution (LTE) became an acknowledged 4G after it was launched in 2009. Some requirements pointed to LTE-Advanced (LTE-A) as the 4G technology; LTE-A was first launched commercially in 2013 [7]. Similarly, it might well be that 5G label will be adopted sometime between 2018 and 2022; someone may probably claim having 5G closer to the earlier date than to the later date. But the important date is when an internationally agreed new standard is available for commercial deployment by operators. This may very well be closer to the later date indicated.

One interesting question is why new generations develop. Is it because of service pull; the mobile network users demand new and better services and therefore the systems must be upgraded and new generation will emerge? Or is it pushed by technology developments so that new generations must be designed to take advantage of the much better performing components and new opportunities? As illustrated in Fig. 2 a "circular reasoning" is perhaps a good answer to both questions; they take place more or less at the same time, with appropriate support from new research activity.

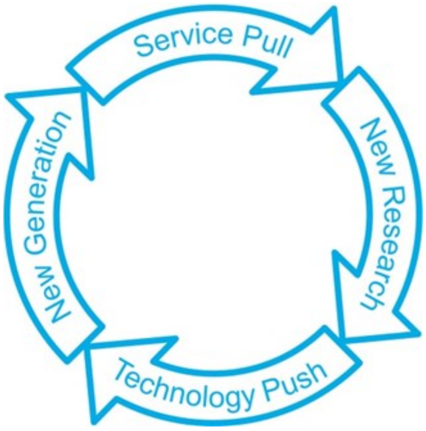

Fig. 2. New generation mobile systems are a result of both service pull and technology push, and appropriate research activity

III. Service pull

Telecommunication networks play an increasingly important role in the society as a key technology enabler for numerous services and functions that must be in place. The future will be no different. People and things will be connected much more strongly than today. Some services will require very large bandwidth, such as new type of high resolution streaming, and some services must be delivered with no perceived latency. Machine communications will continue to grow to very high levels; some of this type of communication may require large bandwidth, such as video, but a lot is expected to be low capacity data traffic. A new network is needed to handle the new type of machine communications as the current has demonstrated severe weaknesses in this respect [8]. Another concern for the numerous low capacity traffic devices is to use protocols being able to deal with the many communications' connections, data and signaling, and to save sensor battery capacity. Clearly, the energy consumption as such is a concern for the whole information and communication technology (ICT) sector as it is for all other sectors and individuals.

IV. New research

In order to set the best path for the next generation systems a lot of research is continuously required . With respect to the network infrastructure the public private partnership on 5G (5G PPP) set up late 2013 with its Technical Annex of agreement, provides a good overview [9]. The 5G PPP indicates that the wireless traffic will be 1000 times larger in 2020 compared to 2010. This figure includes more than the mobile data traffic, but represents anyway a dramatic challenge for equipment developers, mobile network builders and operators. A number of other so-called key-performance-indicators (KPIs) set the scene. Examples are up to 100 times faster individual connections and 1 ms end-to-end latency.

Being part of the broad industry group that prepared the material in the Technical Annex, Telenor is in line with the views expressed by the 5G PPP, Telenor's own research covers topics on 5G flavored by the 5G PPP topics, but limited to a few topics. In the next sections there are more details and some initial results from this research.

A. Innovative network infrastructure

One are of interest for Telenor is how to create innovative network architecture that better enables mobile operations with lower costs, faster service deployment, simplified management and more flexible and efficient usage of the equipment platform. The network must cope with the dramatically growing traffic and scale effectively, and at the same time be much better in reducing cost per delivered service. It should also adapt smoothly to market changes. Software defined networks (SDNs) and network function virtualization (NFV) are an important part of the puzzle in this regard.

While the central idea of SDN is to separate the control plane from the data plane for improved flexibility, NFV is based on decoupling the execution platform from the higher level software such that the underlying compute, storage and networking resources are abstracted and effectively utilized by varying service software. Hence, general purpose hardware can be used leading to lowered costs, faster service delivery time, operational efficiency and more new innovative services. Together the two disruptive technologies, NFV and SDN, have the potential to revolutionize the traditional way of delivering telecommunication services. In the long term, it is very important to work towards a fully integrated IT/Telco virtualized network based on evolved cloud (eCloud) architecture, as illustrated in Fig. 3, where the cloud branches down to small slices hosting access or customer premises equipment functions in the physical locations where they are actually needed. In the center of the eCloud there is a coarse depiction of the pervasive software layering on top of commercial off-the-shelf servers as standard hardware.

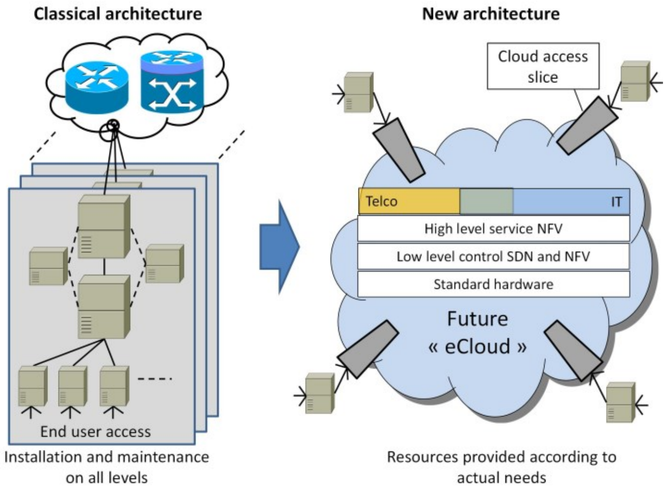

Fig. 3. The classical architecture with physically scattered logic transforms into a more homogeneous, logically centralized and standardized structure, far easier to maintain

Operators are very much active in studying and contributing to this field, such as with the ETSI Industry Specification Group (ISG) NFV, see the latest white paper just issued [10]. It is necessary to make standardized and interoperable solutions, a key interest for the ETSI ISG NFV. From a research point of view, it is important to work more on how the network architecture shall be separating the control plane form the data plane, what actually can be virtualized in a real operation, how to design and standardize the platform for network virtualization and to what extent this type of network can deliver both in economic terms and in traffic terms. Telenor aims at investigating these themes. To this end, a model based on Jackson network is proposed in [11] to investigate the controller to switch interaction in an OpenFlow based SDN for the case in which there is a single node in the data plane. A performance analysis is then carried out using the proposed model which amongst others can answer questions such as how much traffic can be injected into the network for a given delay guarantee (packet sojourn time) and for a known amount of traffic going to the controller? Fig. 4 shows the network throughput achieved for a given delay guarantee, with packet sojourn time being the lower bound, for different amount of new traffic arriving at the date node. q_{nf} in Fig. 4 captures the amount of new traffic arriving at the date node which needs to be processed by the controller. Higher the q_{nf} lesser the throughput as the controller needs to process an extensive work load in terms of packet processing. It also shows that after a certain value of packet sojourn time (1.2 ms) the throughput does not increase.

In addition to the theoretical study on OpenFlow based SDN, an investigation into the economic effects and performance of NFV and SDN enabled networks is being done using Matlab simulations and network simulator (ns-3).

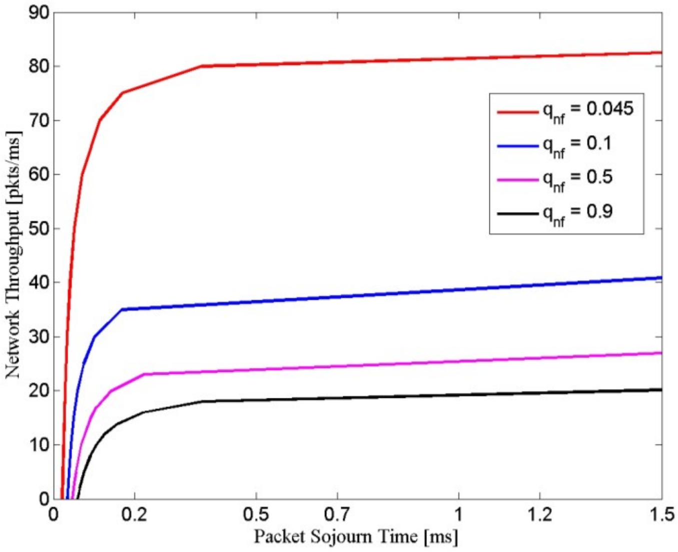

Fig. 4. Dimensioning an OpenFlow enabled SDN [11]

B. Network and radio resource optimization

Crucial to the success of mobile network operations is basic availability of spectrum and the radio resource in general. Although a lot of research results are available there is still plentiful of challenges. Telenor is currently looking in three distinct matters: spectrum sharing, self-organizing network (SON) functions, and improved networking through using more of terminal measurement feedback.

Radio spectrum is obviously of key importance for any mobile operation. Mainly due to scarcity in traditional mobile bands there has been over a lot of research on methods for spectrum sharing in the recent years, particularly in connection with new cognitive radio modems. Spectrum micro trading is one promising technique to enable these spectrum sharing schemes. The potential benefit may be significant from this type of methods [12]. Fig. 5 shows a result of spectrum efficiency depending on the size of the spatial pixels (square side length) in the spectrum auction and method of spectrum allocation. The simulation size is of 2000 runs for a 5 km^2 large area with 15 base stations, each ranging 500 m. It shows that reducing the pixel size results in an increase in the spectrum efficiency for all three auction types. Further, it is shown that using spectrum auctions that optimize allocation can lead to significant increase in spectrum utilization. When maximizing profit the spectrum utilization increases because the bidders having widest coverage area and most connected users are typically those that pay the most. When maximizing spectrum utilization in the spatial area spectrum is allocated to bidders that maximize the total area covered. This might however compromise the total profit and total number of users served [12].

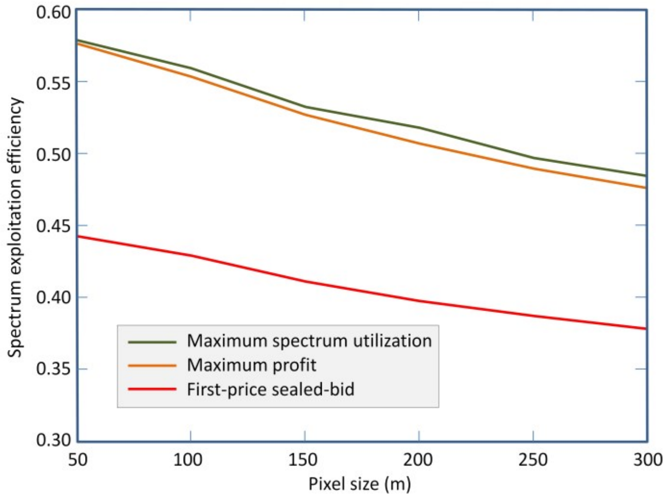

Fig. 5. Spectrum efficiency evaluation deployed as function of pixel sixe and method for assigning frequency to users (Fig. 2c in [12])

With SON functions the network adapts to changing load, failures, or new network elements being added. As time pass by, it is inevitable that networks become more and more complex, hence also more and more difficult to secure its performance. A research topic is to look into how several SON functions collectively will modify and increase the network performance. Fig. 6 illustrates the three functions that all change the size of the cells and hence must co-operate.

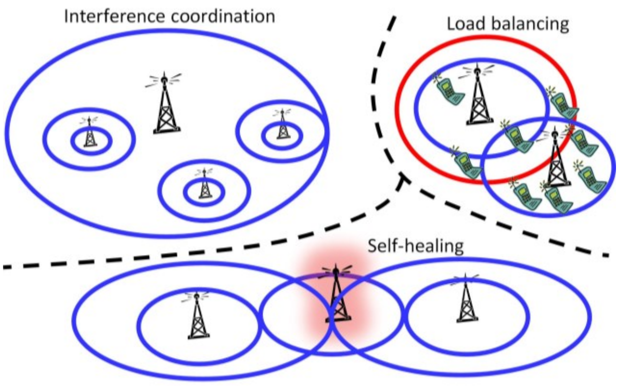

Fig. 6. New generation mobile systems are a result of both service pull and technology pushy, and appropriate research activity

These types of studies are investigated using *ns*-3 simulations and analytical modelling of the network performance. One such result dealt with inter-cell interference of high importance for several aspects of future cellular network structures [13]. By analytical modelling the distribution of the Signal to Interference and Noise (SINR) is derived for several cell layouts ranging from fixed hexagonal grid to highly irregular, by a two dimensional Poisson point process (PP). In the analyses both slow and fast fading are included in the propagation model. In Fig. 7 the coverage probability (or the CDF of the distribution of SINR) is given for two different types of base station layout, either by hexagonal or by using a two dimensional Poisson PP. The figure illustrates the coverage probabilities for the two extreme layouts, namely hexagonal and Poisson PP, as function of the SINR and shows the huge difference in the coverage probabilities between those extremes.

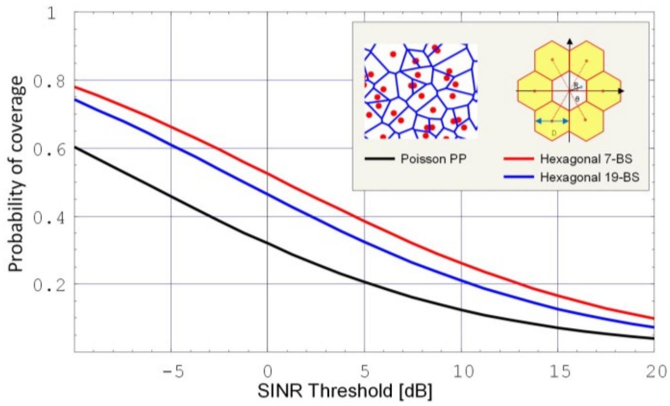

Fig. 7. Coverage probability for two different schemes of base station layouts in an environment described by shadowing standard deviation of 9 dB (simplified version of Fig. 6 in [13])

A major design challenge in the future mobile system will be to implement an efficient radio resource management, of which the packet scheduler is an important component. On one hand the resource allocation flexibility in both the time and frequency domain can be exploited while at the same time the scheduling algorithm should take into account the QoS requirements of the connected devices. To this end a scheduling algorithm, labelled FTGS in Fig. 8 is implemented in [14]. It provides long-term throughput guarantees to the different users, while opportunistically exploiting the instantaneous channel fluctuations to increase the cell capacity. A thorough performance analysis is performed in [14] comparing FTGS algorithm with the other well-known algorithms (like maximum throughput scheduler (MTS), blind equal throughput scheduler (BETS), proportional fair scheduler (PFS)) by means of extensive *ns*-3 simulations, both for saturated UDP and TCP traffic sources. The analysis makes it possible to appreciate the difference among the scheduling algorithms, and to assess the performance gain, both in terms of cell capacity and packet service time, obtained by allowing the schedulers to work in the frequency domain. A snapshot of this analysis is shown in Fig. 8 where the tradeoff between cell throughput and fairness for the different scheduling algorithms is highlighted. Although FTGS performs somewhat similar to PFS in terms of throughput, but it is superior to PFS when it comes to fairness. Furthermore the fairness is slightly reduced with TCP traffic for all the schedulers.

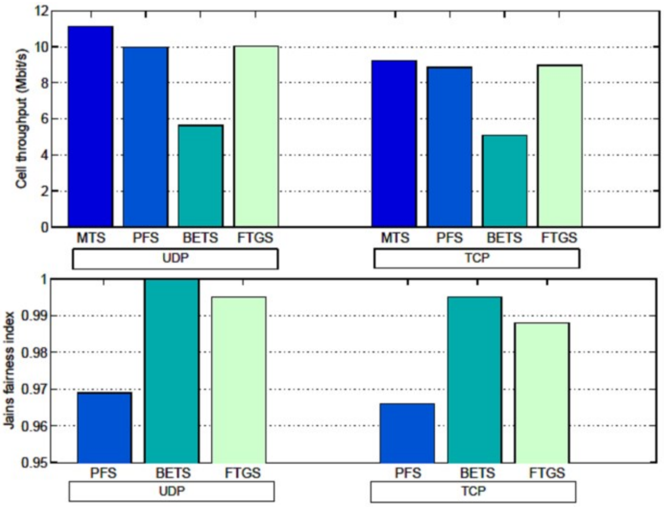

Fig. 8. Cell throughput and fairness achieved by the four considered schedulers [14]

In a new approach, in the collaboration with Chalmers Antenna Systems Excellence Center (Chase) [15], the aim is both to improve mobile handset antennas and network performance through collection of data from hand-sets over the air (OTA), see Fig. 9. Telenor is particularly engaged in developing a new app to collect more and new data from the handset for the purpose to both improve the network performance and equipment (handsets).

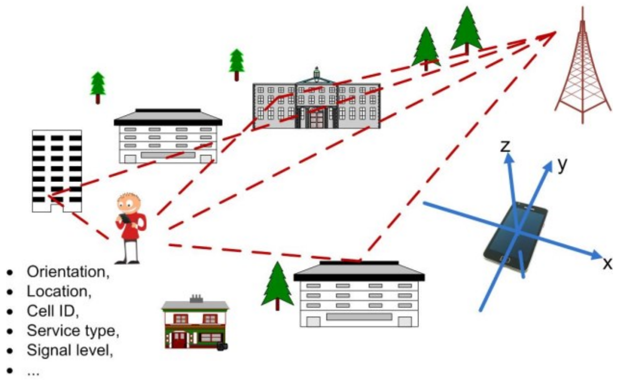

Fig. 9. Improving network performance by handset information

First results include statistics on handset orientation from data collected from handset in a real network [16]. Device performance will affect overall network performance; it will also affect the total capacity of the network since end users with bad devices are degraded to lower modulation and coding schemes.

C. Network capacity and traffic handling

It is important to always build high efficient networks. The future seems to become more complex also with respect to radio access technology. Therefore an operator must be better in utilizing heterogeneous networks, both combinations of macro cell and small cell, and also mobile combined with other wireless technology (i.e., Wi-Fi). The gross throughput traffic depends clearly on many aspects, but interference handling is important [13].

Another topic is backhaul. With an increasing number of users the only possible solution often means shrinking the cell sizes to smaller areas. The result is many more base station sites. Connecting these represent an increasing challenge in terms of technology as well as cost. Radio links are one of the most used technics to feed the base stations currently. Telenor investigates various aspects of backhaul technologies. One experimental work is to use 70/80 GHz radio links for providing gigabit capacity [17]. Fig. 10 illustrates results comparing attenuation (in dB) measurements with current rain attenuation prediction methods for a 3.5 km line-of-sight radio link. The upper part of the figure shows the predicted attenuation exceeded at 0.02 %, 0.1 %, and 1 % of the year. The lower part shows prediction error = predicted – measured (in dB) It seems that the prediction underestimates the observed attenuation. There are several likely reasons for this, see [17], where it, after all, also seems to be that the rain attenuation prediction method is too optimistic. Measurements like these are very important for future gigabit backhaul technology. There are very few multi-year measurements available for this high frequency range and virtually no other multi-year measurements available from a real link set-up.

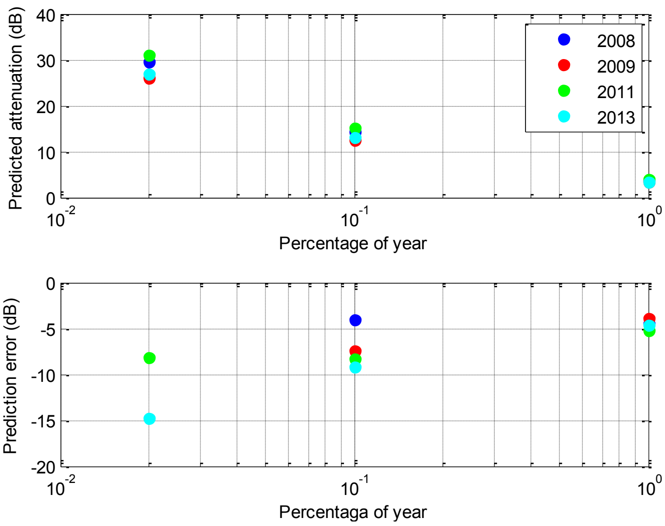

Fig. 10. Predicted rain attenuation for a 3.5 km radio link at 83 GHz and prediction errors comparing with a 4 year measurements

V. TECHNOLOGY PUSH

Technology push has many aspects from basic research to standardization. In the context of this paper, it is the internationally agreed standards that in the end make it possible for new generation technology to be pushed through. The 3rd generation partnership project (3GPP) [18] started as an ETSI project, but is today the global arena for developing the new standards of mobile communication with participation from all important regional organizations. Also standardization activity at the Internet Engineering Task Force (IETF) to define the future all Internet mobile solution, and at the

Radiocommunication Sector of the International Telecommunication Union (ITU-R) world radio conferences (WRC) where the global utilization of spectrum is set.

VI. Conclusion

This paper presents some views on next generation mobile, 5G, focusing on research topics selected by Telenor. It includes some recent results achieved on

- innovative network architecture utilizing network virtualization,
- network and radio resource optimization covering self-organized networks, inter-cell interference coordination, traffic throughput for various scheduling schemes, and how real time terminal measured information can enhance performance, and
- some aspects of network capacity and traffic handling such as backhaul gigabit link dimensioning.

From a research point of view it is time to prepare the next generation, and identify the best possible solutions to meet the KPIs set out.

Acknowledgment

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