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B4G local area: high level requirements and system design

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Abstract—**A next generation Beyond 4G (B4G) radio access technology is expected to become available around 2020 in order to cope with the exponential increase of mobile data traffic. In this paper, research motivations and high level requirements for a B4G local area concept are discussed. Our suggestions on the design of the B4G system as well as on the choice of its key technology components are also presented.**

Index terms- ***B4G, RAT, local area, HetNet, IMT, 3GPP, LTE-A, MIMO, TDD, OFDM, link adaptation, HARQ, ICIC, synchronization***

I. INTRODUCTION

From a study on long term historical progress within information technologies [1], annual growth rates in the order of 25-40% for several evolution laws have been found (e.g, memory, digital processing power, radio frequency circuitry). Such a long term review provides probably the best number to also predict progress in the Radio Access Technology (RAT) for mobile communication for the next decades.

Assuming a conservative annual growth rate of 25% in the progress of mobile communications technology, we obtain a factor of ~x10 during a decade and a factor of ~x100 over two decades. A more aggressive growth rate (40%) leads to a factor of ~x30 over a decade and almost a factor of ~x1000 over two decades [2]. Such multiplicative factors seem valid for RAT evolution from 1st generation (1G) to 4th generation (4G); this has motivated the introduction of a new disruptive RAT every decade to take full advantage of the technology progress without legacy burden.

The 3rd Partnership Project Long Term Evolution - Advanced (3GPP LTE-A) standard is generally agreed to be the 4G mobile communication technology [3], and its specifications were submitted to the International Telecommunication Union (ITU) back in 2010 to be included into the International Mobile Telecommunication Advanced (IMT-Advanced) family. From a research perspective it is hence time to look into what should be the high level requirements and technology components for a next generation Beyond 4G (B4G) RAT to become available around 2020.

This paper presents our initial considerations on how a B4G technology should look like. High level requirements are presented, and design criteria and key technology components for an efficient system design are also discussed.

The paper is structured as follows. Section II describes and motivates the general requirements for a B4G concept. Section III presents the Heterogeneous Network (HetNet) deployment which motivates our particular focus on local area scenarios. Section IV introduces the high level system design criteria for B4G local area, while Section V describes main candidates technology components. Finally, Section VI resumes the conclusions.

II. B4G REQUIREMENTS

A. Technology requirements

Based on the technology progress discussion in the previous Section, we estimate the requirements for a B4G RAT to be ~x10 times better than the current 4G generation, i.e., LTE-Advanced:

- Peak data rates should be in the order of 10 Gbit/s
- Round Trip Time (RTT) should be in the order of 1ms
- Wake-up time from "inactive" to "active" should be in the order of 10 ms

B. User requirements

The peak performance is usually achievable only in extremely favorable conditions which may seldom appear in a real deployment. Besides the peak targets, it is then extremely important to define more practical requirements for the user satisfaction.

In today's standard, we estimated that the minimum downlink (DL) data rate not to make users unhappy are in the order of 1 Mbit/s at application level. By using the factor ~x10, we should expect the minimum DL data rates to be in the order of 10 Mbit/s in year 2020.

We estimate that by around 2020 most data applications will demand "always on"; from an end-to-end delay perspective, communications involving human interaction seem to require a setup delays of less than 30 ms. However, Machine-to-Machine (M2M) type of communication [4] would still benefit from much lower end-to-end delays.

C. Capacity requirements

The B4G capacity requirements need to consider both the increase in user demand and the increase in number of users. To model the increase in traffic volume, we have used an exponential function to estimate the user requirements, an S-

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curve [5] to model the penetration rate of mobile broadband users and another exponential curve to estimate the increase of total mobile subscriptions. Using values of 25% or 40% in user traffic volume increase Year over Year (YoY), increasing mobile broadband penetration from 15% (2010) to 100% in 2020 and the number of mobile subscriptions by 10% YoY, we then predict a factor of ~x160 to ~x500 in the mobile traffic volume by 2020 (relative to 2010). From Figure 1 it can be seen that, due to the S-curve impact, the annual average traffic volume increase is still in the order of 100% or more for the next few years, whereas it will convert to be in the order of approx 40-50% in the long term. This simple model of traffic volume seems to fit well with factual numbers of today and traffic predictions by other sources.
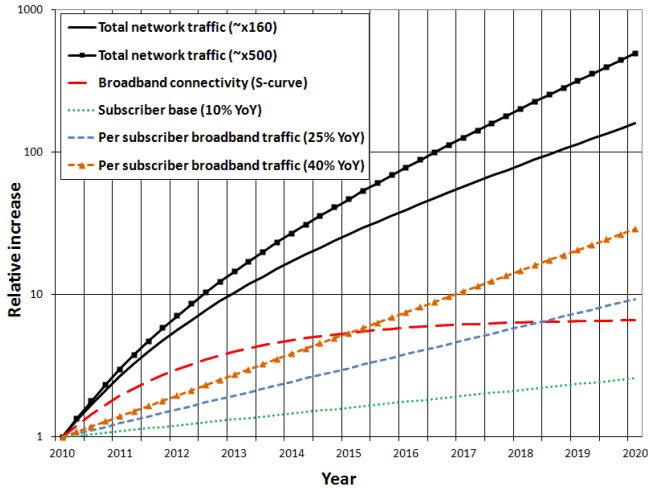

Figure 1. Estimated broadband traffic growth.

III. HETNET DEPLOYMENT

It is generally anticipated that the increase in network capacity comes from the "capacity cube": higher spectral efficiency per link, more frequency spectrum and more cells.

It is our current understanding that the main contributor to higher spectral efficiency is Multiple-Input-Multiple-Output (MIMO) antenna technology [6]. In theory, the spectral efficiency of MIMO scales linearly with the number of antennas. Unfortunately, the technology progress which allows multiple antennas and radio frequency (RF) circuitries to be included in the same device is rather slow. Moreover, MIMO also tends to require significant increase in receiver complexity and control signaling overhead. We then predict that practical implementation of MIMO enabled products is developing much slower than what has been specified, e.g. in LTE-Advanced (including 8x8 MIMO) [3]. As today 2x2 MIMO is the *de facto* standard in LTE products, for 2020 we expect 4x4 to have become default implementation, which is approximately doubling the spectral efficiency compared to LTE-A.

Large frequency spectrum is a straightforward method to improve capacity. Low frequency bands (paired) provide very good coverage, but are indeed a more scarce resource than high frequency bands (potentially unpaired). Also MIMO is easier to be implemented at higher frequency bands from a form factor perspective. From both a coverage and RF technology

perspective, it is desirable to explore new IMT frequency spectrum for B4G at the next potential band. Currently the frequency band from 3.4-4.9GHz has drawn high attention for increasing capacity of IMT systems. Total IMT spectrum would approximately double by including the 3.4-4.9GHz bands by 2020.

Given the relatively limited impact of MIMO and larger spectrum, increasing the number of cells is probably still the largest contributor to the network capacity. The amount of traditional macro sites, which are expected to provide basic service coverage to ensure voice and data services, is unlikely to increase significantly in urban areas, i.e., less than doubling. We estimate that outdoor micro cells will play an important role in achieving high data rate everywhere, e.g. 10 Mbps @ 90% coverage; the number of out-door micro sites may likely become in the order ~x10 times the number of macro sites. Moreover, today mobile data traffic is mostly generated by indoor users and it is generally anticipated that the indoor/outdoor traffic share is in the order of 70%:30% or even higher. Indoor cells (e.g., femtocells) have however several properties which are very different from out-door cells. For instance, the output power of indoor cells must be kept very low due to health regulation issues; moreover, the indoor propagation is more sensitive to signal attenuations because of wall and floor penetrations. As a consequence, the coverage can be very limited and a very high number of cells must be deployed to ensure efficient traffic capturing to off-load the outdoor cells. From HetNets analysis we predict that indoor cell density shall be more than ~x100 times the macro sites density. Table 1 summarizes the relative densities of macro, micro and indoor cells, as well as their downlink transmit power.

TABLE 1. RELATIVE DENSITIES OF RADIO CELLS

Relative density	Downlink transmit power
~x1 macro cells	40-46 dBm
~x10 micro cells	30-40 dBm
~x100 indoor cells	10-20 dBm

In LTE-Advanced release 10 and 11, high emphasis was put on the co-channel interference coordination between multiple layers of a HetNet. When the cell density increases by a factor of ~x10 comparing one layer to another, our analysis shows that it is recommended to use dedicated spectrum for each layer and use the lower frequency band for macro and the highest band for indoor cells. Moreover, we believe there is no point in allocating excessive amount of spectrum to improve small cells layer, as this may just result in service outage for users served by the macro layer due to lack of spectrum. From HetNet analysis we have also observed that we need to apply relatively aggressive traffic steering towards the network layer with higher cell densities.

To sum up, we foresee a massive deployment of indoor cells working on a dedicated spectrum as the solution for meeting the high capacity requirements. Furthermore, system scalability becomes very important given the expected high density of cells. These considerations justify our focus on a stand-alone indoor local area (LA) B4G concept.

IV. B4G LA SYSTEM DESIGN REQUIREMENTS

We reasonably believe that the traditional access between a Base Station (BS) and a User Equipment (UE) will still be the main access method in B4G LA concept. It is difficult to predict whether the average asymmetry of approx ~1:6 between UL and DL will remain in the future or whether it will become more symmetrical or asymmetrical. Hence it is important to keep UL and DL capacity fully flexible.

In terms of spectrum, we see it natural to target but not limit to the next available/potential frequency band of 3.4-4.9GHz. For instance, the system should be designed to cope with increasing phase noise at even higher band than 5GHz, up to 10-15GHz.

We believe that the optimized usage of unpaired spectrum will clearly be one of the focus areas for the B4G air interface design. This makes a difference compared to LTE/LTE-A design where Time Division Duplex (TDD) and Frequency Division Duplex (FDD) modes have been greatly harmonized and the degree of TDD specific optimization has been minimized.

We foresee significant advantages of using TDD mode for enabling further communication links besides traditional UE-BS access (i.e., self-backhauling by means of BS-BS communication, peer-to-peer UE-UE communication without infrastructure). The main goal of the TDD optimization would be to maximize the similarity of the different radio links illustrated in Table 2. This implies the usage of a link-independent access scheme. Moreover, similar control and reference signal structures as well as the same transmit waveform could be used for all radio links. System design and hardware implementation is then simplified, and inbuilt support for relaying is provided inherently. Thus, having a link independent air interface design would be an enabler supporting several use cases and gain mechanisms.

Finally, due to the very high estimated number of B4G LA BSs, deployment and optimization should be "plug and play". The BSs should be able to autonomously detect the neighboring cells and thus enable coordinated operations with them. Moreover, mobility of the UEs across multiple cells should be supported in case of open subscriber group (OSG) scenario. The UEs may be connected to a macro cell carrier, but should be able to detect inter-frequency indoor cells and connect to them when moving in their coverage area.

TABLE 2. RADIO LINKS FOR B4G LOCAL AREA

Transmit	Receive	Link type
B4G BS	B4G UE	Traditional downlink
B4G UE	B4G BS	Traditional uplink
B4G BS	B4G BS	Self-backhauling
B4G UE	B4G UE	Device to device

V. TECHNOLOGY COMPONENTS

The optimization of a number of technology components is needed for achieving the B4G LA requirements. WiFi and LTE-A can be considered as main reference for our system; however, their baseline components are not designed for achieving the targeted performance in local area. WiFi is a relatively simple and cheap technology [7] which does not scale well to dense deployment, mainly due to its contention-based access characteristic as well as its inability to coordinate across multiple access points. On the other side, LTE-A is a scheduled system which is mainly optimized for wide area; this means, its signaling overhead may be redundant for a pure local area system. In the following, the main technology components which need to be optimized for achieving our targets are briefly described, by bearing in mind their practical feasibility in commercial products.

A. Modulation

Orthogonal Frequency Division Multiplexing (OFDM) modulation format [8] has achieved widespread acceptance among numerous wireless communication standards given its capability of converting the time dispersive channel to a number of narrowband frequency domain flat channels, thus enabling simple one-tap equalization at the receiver as well as straightforward extension to MIMO. However, OFDM also presents some disadvantages such as a considerably high Peak-to-Average Power Ratio (PAPR), high Out-of-Band emissions, sensitivity to frequency offset, throughput losses due to the insertion of a Cyclic Prefix (CP) at the beginning of each symbol. Recently, the usage of filterbank multicarrier modulation [9] has been discussed as an alternative to OFDM. Filterbank multicarrier modulation does not use CP thus avoiding throughput losses, and can be designed for having better spectral containment for enhancing the spectrum reusability. However, their time domain processing may increase up to 10 times the latency and computational complexity with respect to OFDM. Given the latency and cost-effectiveness requirements of B4G small cells, we believe that OFDM has still to be considered as the strongest candidate access technology.

B. Frame structure

Our ambitious RTT requirement (1 ms) leads to the definition of a very short frame (0.5 ms). Such short frame also helps in reducing the duration of any hand-shaking procedure between UE and BS (e.g, wake-up time). According to what stated in Section IV, our frame should be flexible enough to accommodate different UL/DL ratios; this means, a large number of OFDM symbols need to be accommodated. For instance, for a target of 16 OFDM symbols, a symbol duration of around 31 μs is foreseen. Generally, a very short CP (e.g. 0.5 μs) can be assumed to cope with the expected delay spread of local area environments. Nevertheless, a longer CP may still be needed for instance to cope with different propagation delays in case a timing advance procedure [10] is not applied. We believe it may be worth having a slightly longer CP and saving some complexity due to the signaling hand-shaking in a timing advance procedure. Note that the short time symbol duration makes it also very robust to phase noise which potentially limits the achievable Signal-to-Noise Ratio (SNR) at high carrier frequency.

In addition to the frame length, the RTT is affected by the processing time. In order to minimize it, the demodulation reference signals as well as data-associated control signaling

should be located before the data. This allows for pipeline processing in the receiver, which is important considering the cost-efficiency requirement.

In principle, the UL/DL ratio can be set statically or dynamically on a frame basis. Moreover, the frame should leave space to contention based slots as well as UE-to-UE communication slots. The most critical UL/DL signaling can be allocated in a "protected part"; for example, each network node transmits its signaling in the first symbols of the frame regardless of the effective UL/DL ratio. By this way, the signaling can be designed to be robust to interference from neighboring BSs, assuming they are time synchronized.

The expected switching time of future RF circuitry should also be taken into account when designing the guard time between DL and UL slots. The suggested frame structure is shown in Figure 2, assuming three links with different UL/DL ratios.
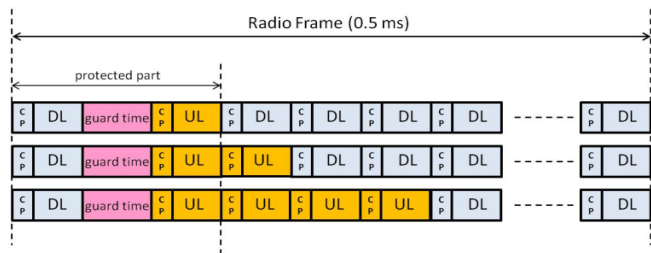

Figure 2. Radio frame structure for three different links.

C. Link adaptation and HARQ

The high spectral efficiency of modern wireless standards such as LTE/LTE-A is partly due to the possibility of adapting the data rate to the instantaneous channel conditions. In LTE-A, a different Modulation and Coding Scheme (MCS) can be selected for each frame. In principle, the overall temporization of link adaptation may be relaxed, given the large expected coherence time in local area. However, we still believe it is worth to perform link adaptation on a frame basis. Since fast link adaptation allows usage of the highest possible data rate according to the channel conditions, it shortens transmissions, reduces the power consumption and minimizes the usage of orthogonal resources. Hybrid Automatic Repeat Request (HARQ) shall also be included since it allows to tolerate a higher Block Error Rate (BLER) target. In LTE TDD, the HARQ soft buffers can be very large since up to 15 processes can run in parallel, and retransmission delay varies according to link direction, frame number, and UL/DL configuration. Since the large buffers represents the main cost of the baseband modem and the high data rate target of B4G may further increase the memory requirement, we believe that the number of HARQ processes shall be minimized.

D. MIMO techniques

MIMO is nowadays universally considered as a fundamental technology component for meeting the ambitious upper data rate target of modern wireless communication standards [6].

The degrees of freedom given by the multiple antennas on both sides of the communication link may enable multiple stream transmission in case of high SNR conditions as well as

precoding and diversity solutions for improving the link robustness. As mentioned in Section II, we believe that realistically 4x4 single user or multiuser MIMO can be deployed cost-efficiently in a device. While open loop spatial multiplexing mode can boost the spectral efficiency by transmitting up to 4 data streams over the channel, precoded MIMO can exploit some degree of channel knowledge at the transmitter side for improving the SNR of the streams. Moreover, coordinated Multipoint (CoMP) techniques [11] have recently drawn considerable attention by both academia and industry as a solution for further improving the coverage. The main idea of CoMP is to coordinate the transmission of multiple BSs towards the same UEs, as well as processing the signals sent by the same UE and received by the multiple BSs. CoMP requires some signaling among the BSs and may boost the backhaul requirements. The effectiveness of CoMP within an interference-limited massive deployment is still under evaluation.

E. Channel reciprocity

In TDD mode, it is possible to exploit the channel reciprocity for avoiding feedback overhead in a number of applications, e.g. for precoded MIMO. For example, the UE can estimate the channel response from the pilot symbols sent in the downlink and derive its optimal precoding matrix according to it. In order to maximize benefits of channel reciprocity, the number of transmit and receive ports in a network node should be always the same. However, the cost effectiveness of radio frequency front ends in both transmit and receive chains may compromise the channel reciprocity. An hardware calibration procedure is then necessary for aligning both chains to a common reference [12]. Calibration should be performed at a faster rate than the rate of change of gain and phase hardware; such rate is expected to be much lower than the channel state indicator (CSI) feedback temporization. Since absolute calibration to an external reference is not feasible in practice, an over-the-air procedure should take place. Some of the known approaches are based on exchange of sounding packets between the radio stations, which apply correction coefficients that align their channel estimates.

F. Interference mitigation

As mentioned in Section III, B4G BSs will need a large spectrum in order to boost capacity. On the other hand, spectrum is a scarce and expensive resource and probably it will not be possible to univocally assign large and independent bands to each operator. Since a bandwidth of at least 200 MHz is foreseen for achieving a top data rate of 10 Gbit/s, operators may benefit from sharing the same spectrum. However, the nature of spectrum sharing inherently increases the interference levels, especially in a massive deployment, leading to poor network performance. Inter-cell interference Coordination (ICIC) techniques are then expected to be adopted in B4G LA. Recently, a number of distributed cognitive approaches for frequency domain ICIC have been proposed in literature and also discussed within the standardization bodies. Examples of distributed ICIC

algorithms are Autonomous Component Carrier Selection (ACCS) [13], or Self-Organizing Coalitions for Conflict Evaluation and Resolution (SOCCER) [14]; these solutions are also compliant with the concept of self-organizing network, where the network nodes are able to achieve a certain organization level without relying to any centralized external entity, thus suiting the plug-and-play paradigm. Note that the problem of mitigating interference can be tackled on a pure receiver perspective rather than with a network coordination scheme. Receiver solutions such us Interference Rejection Combining (IRC) [15] or Successive Interference Cancellation (SIC) [16] are already well established within the engineering community. However, these receivers are typically able to suppress or cancel a limited number of interferers (e.g., lower than the antenna cardinality), and therefore may not completely replace a smart interference coordination solution. A cost-efficient design should address a practical trade-off between ICIC and realistic interference suppression capabilities of the baseband receivers.

G. Importance of time synchronization

Time synchronization at OFDM symbol level among the different BSs can enable efficient interference coordination. Moreover, it eases mobility by allowing the UEs to keep track of the receive quality of the reference signals sent by multiple BSs, and can enable some of the advanced techniques listed above (e.g., robust signaling, CoMP, interference cancellation, etc.). We are targeting an accuracy of a fraction of μs in order to keep the BSs aligned within the CP length.

In principle, a Global Positioning System (GPS) reference for the BSs can achieve the targeted accuracy level. Nevertheless, the penetration losses of the GPS signals indoor may strongly affect the feasibility of such a "centralized" solution for our local area scenario. Similarly to the spectrum sharing problem, self-organizing distributed algorithms have then to be analyzed as a suitable option for network synchronization [17]. Given our ambitious accuracy target, solving the initial synchronization problem may not be sufficient for keeping the BSs aligned in the long term. Accuracy of the local oscillators built on the commercial devices is of the order of 5-10 ppm; this means, their timing functions may drift considerably if a runtime correction procedure is not applied.

VI. CONCLUSIONS

From long term prediction of mobile communications technology, we have proposed an annual progress of 25%, which approximately corresponds to a factor of ~x10 in the evolution over a decade. We have estimated the user demand to follow the same trend, as well as the growth in mobile traffic volume to be in the order of ~x160 by 2020 (with reference to 2010). To provide the necessary capacity after 2020, we have predicted that low power indoor cells will need to carry a substantial part of the total traffic volume. We have then suggested requirements and technology components to be considered for a novel B4G local area radio access technology. We focus on TDD mode, since it maximizes the

similarity of the different radio links. OFDM is still to be considered the most promising modulation scheme, while the frame structure should be very short and ensure at the same large flexibility for the allocation of UL/DL slots. Advanced MIMO techniques are necessary to cope with link spectral efficiency requirements, as well as for improving the link robustness. Fast link adaptation and HARQ can boost the throughput but need to be designed with the aim of reducing power consumption and baseband buffering requirements. Channel reciprocity in TDD mode can be exploited for reducing the control feedback overhead, while interference mitigation should be tackled from both resource management and signal processing perspectives. Finally, fine network synchronization is to be considered an important enabler for the advanced B4G features.

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