LTE-Advanced – Evolving LTE towards IMT-Advanced

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Abstract— **This paper provides a high-level overview of some technology components currently considered for the evolution of LTE including complete fulfillment of the IMT-Advanced requirements. These technology components include extended spectrum flexibility, multi-antenna solutions, coordinated multi-point transmission/reception, and the use of advanced repeaters/relaying. A simple performance assessment is also included, indicating potential for significantly increased performance.**

Keywords-LTE, IMT-Advanced, LTE-Advanced, 4G

I. INTRODUCTION

The 3GPP Long Term Evolution (LTE) [1][2] is a highly flexible radio interface with initial deployments expected in 2009. As the work on the first release of the LTE standard is coming to an end, the focus is now gradually shifting towards the further evolution of LTE, referred to as *LTE-Advanced*. One of the goals of this evolution is to reach and even surpass the requirements on IMT-Advanced, as currently being defined by ITU-R [3]. These requirements will include further significant enhancements in terms of performance and capability compared to current cellular systems, including the first release of LTE.

In this paper, some potential key technology components for the LTE evolution towards LTE-Advanced are being discussed.

II. REQUIREMENTS

IMT-Advanced is the term used by ITU for radio-access technologies beyond IMT-2000 and an invitation to submit candidate technologies for IMT-Advanced has been issued by ITU [5]. Anticipating the invitation from ITU, 3GPP already in March 2008 initiated a study item on *LTE-Advanced*, with the task of defining requirements and investigating the technology components of the evolution of LTE, an evolution including extending LTE to meet all the requirements of IMT-Advanced as defined by ITU.

Being an *evolution* of LTE, LTE-Advanced should be backwards compatible in the sense that it should be possible to deploy LTE-Advanced in spectrum already occupied by LTE with no impact on existing LTE terminals. A direct consequence of this requirement is that, for an LTE terminal, an LTE-Advanced-capable network should appear as an LTE network. Such spectrum compatibility is of critical importance for a smooth, low-cost transition to LTE-Advanced capabilities within the network and is similar to the evolution of WCDMA to HSPA.

Apart from the requirement on backwards compatibility, LTE-Advanced should fulfill and even surpass all the IMT-Advanced requirements in terms of capacity, data rates and low-cost deployment. This includes the possibility for peak data rates up to 1 Gbit/s in the downlink and 500 Mbit/s in the uplink. However, more important than the peak data rates is the possibility to provide high data rates over a larger portion of the cell.

III. TECHNOLOGY COMPONENTS

The link performance of current cellular systems such as LTE is already quite close to the Shannon limit. From a pure link-budget perspective, the very high data rates targeted by LTE-Advanced require a higher SNR than what is typically experienced in wide-area cellular networks. Although some link improvements are possible, e.g. using additional bandwidth as a means to improve the coding/modulation efficiency, it is necessary to find tools for improving the SNR, e.g. by means to allow for a denser infrastructure at reasonable cost. In the following subsections, some examples of technologies considered for LTE-Advanced are outlined.

A. *Wider-band transmission and spectrum sharing*

Already the first release of LTE radio-access specification provides extensive support for deployment in spectrum allocations of various characteristics. Thus, LTE can be deployed in spectrum allocations of different size, with transmission bandwidths ranging from around 1.25 MHz, suitable for initial migration of e.g. cdma2000/1xEV-DO systems, up to around 20MHz, needed to provide the highest LTE data rates of 300 Mbit/s. Furthermore, LTE allows for operation in both paired and unpaired spectrum by providing a single radio-access technology supporting Frequency-Division Duplex (FDD) as well as Time Division Duplex (TDD). In TDD mode-of-operation, LTE also achieves full spectrum compatibility with the current 3GPP TDD-based TS-SCDMA radio-access technology.

The very high peak-data rate targets for LTE-Advanced can only be fulfilled in a reasonable way with a further increase of the transmission bandwidth, compared to what is supported with the first release of LTE, and transmission bandwidths up to 100 MHz have been discussed in the context of LTE-Advanced. At the same time, such a bandwidth extension should be done while preserving spectrum compatibility as discussed in Section II. This can be achieved done with so-called *carrier aggregation*, where multiple LTE “component carriers” are aggregated on the physical layer to provide the necessary bandwidth. Carrier aggregation is illustrated in Figure 1. To an LTE terminal, each component carrier will

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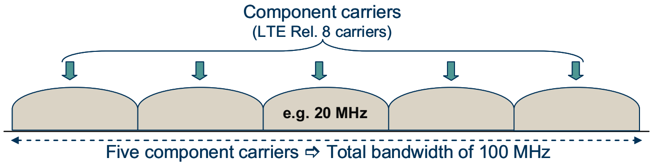

Figure 1. Example of carrier aggregation.

appear as an LTE carrier, while an LTE-Advanced terminal can exploit the total aggregated bandwidth.

In Figure 1, the case of contiguous component carriers is illustrated although, from a baseband perspective, this is not a prerequisite. Access to large amounts of contiguous spectrum, in the order of 100 MHz, may not always be possible. LTE-Advanced could therefore allow for aggregation of non-contiguous component carriers in, possibly, separate spectrum (*spectrum aggregation*) to handle situations where large amounts of contiguous spectrum are not available. However, it should be noted that aggregation of non-contiguous spectrum is challenging from an implementation perspective. Thus, although spectrum aggregation would be supported by the basic specifications, the actual implementation will be strongly constrained, including specification of only a limited number of aggregation scenarios and aggregation over dispersed spectrum only being supported by the most advanced terminals.

For a component carrier to be accessible by an LTE terminal, synchronization signals and broadcast channels need to be present. On the other hand, for an LTE-Advanced terminal capable of receiving multiple component carriers, it is sufficient if these signals are available on one of the component carriers only. Hence, an operator can, by enabling/disabling synchronization signals, control which part of the spectrum that should be accessible to LTE terminals. Whether carrier aggregation is used or not, and which component carriers to aggregate, is provided to the LTE-Advanced terminals as part of the system information.

Finally, note that access to higher transmission bandwidths is not only useful from a peak-rate perspective, but also, and probably more important, as a tool for extending the coverage of medium data rates. As an example, assume a data rate requiring the use of higher order modulation and/or high code rates in LTE. With access to higher bandwidths, the same data rate may be possible to provide with power-efficient QPSK modulation and/or lower code rate, both impacting the link budget favorably.

B. *Multi-antenna solutions*

Multi-antenna technologies, including beam-forming and spatial multiplexing, are key technology components already of LTE and can safely be expected to continue to play an even more important role as part of LTE-Advanced. The current LTE multi-antenna design supports up to four antenna ports with corresponding cell-specific reference signals in the downlink, in combination with codebook-based precoding. This structure supports both spatial multiplexing of up to four layers, implying peak-data rates of 300 Mbit/s, as well as (codebook-based) beam-forming. Together with a total bandwidth of 100 MHz, the current LTE spatial multiplexing schemes would result in a peak rate of 1.5 Gbit/s, well beyond the LTE-Advanced requirement.

As a minimum, support for spatial multiplexing on the uplink is anticipated to be part of LTE-Advanced. The reason for this is that even by just considering the ITU requirements, uplink spatial multiplexing is, in practice, needed to fulfill the peak spectral-efficiency targets.

Increasing the number of supported downlink transmission layers beyond four is possible, and can be used as complement to a peak-rate increase through bandwidth expansion. However, spatial multiplexing of a large number of transmission layers to a single terminal is mainly useful in high-SNR scenarios found in close proximity to a base station or in specific scenarios such as small cells or fixed wireless deployments. At the same time, a more relevant target is to improve the wide-area data rates. Hence, improved support for beam-forming as a tool to increase the SNR at the receiver and to employ spatial multiplexing within the beam is in many situations more important than increasing the number of transmission layers alone. Codebook-based beam-forming with cell-specific reference signals may result in excessive overhead if more than four antennas are used and improved support for UE-specific reference signals may therefore be attractive for LTE-Advanced.

C. *Coordinated multi-point transmission*

As mentioned at the beginning of Section III, the data rates targeted by LTE-Advanced require a (significant) improvement in the SINR at the terminal. Beam-forming is one possibility. Already in current networks, multiple, geographically dispersed antennas connected to a central baseband processing unit are used as a cost-efficient way of building networks. Such structures open up new transmission strategies.

With the base band processing located in a single node, *coordinated multi-point transmission/reception* (CoMP), illustrated in Fig. 2, can be deployed. In the downlink it implies coordination of the transmissions from multiple transmission points. Depending on to what extent the terminals are aware of transmissions originating from multiple points, three different alternatives, A, B, C, can be envisioned.

In alternative A, the terminals are not aware of the transmission originating from multiple, geographically separated points. The same receiver processing and measurement reporting as for single-point transmission is used. Hence, in principle, the introduction of multi-point transmission can be made in a backwards compatible way, benefiting also existing LTE terminals. The network can, e.g. based on existing pathloss measurements, determine from which transmission points to transmit to a specific terminal. As the terminals are not aware of the presence of multipoint transmission, UE-specific reference signals, available already in the first release of LTE, has to be used for channel estimation. In this setting, coordinated multi-point transmission provide diversity gains similar to those found in single-frequency broadcast networks and results in improved power-amplifier utilization in the network, especially in a lightly

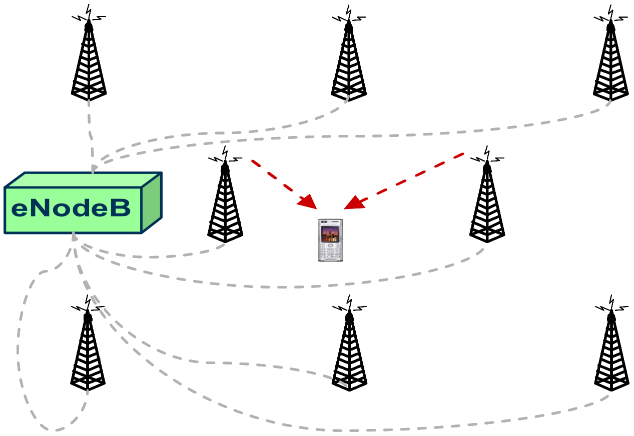

Figure 2. Coordinated multi-point transmission.

loaded network where otherwise some power amplifiers would be idle.

In alternative B, the terminals provide channel-status feedback to the network for all downlink channels visible to a particular terminal while the receiver processing remains the same as for single-point transmission. At the network side, as all processing is located in a single node, fast, dynamic coordination of the transmission activity at the different transmission points is possible. One possibility is to do spatial prefiltering of the signal transmitted to a particular terminal to reduce inter-user interference, possibly also complemented by dirty paper coding [8]. This type of coordinated multi-point transmission can in principle provide similar benefits as alternative A above but, in addition to improving the strength of the desired signal, it also allows for coordinating the inter-user interference to further improve the SNR. Since the terminal is not aware of the exact processing in the network, UE-specific reference signals are needed.

In alternative C, the channel-status reporting is the same as in approach B. However, unlike approach B, the terminals are provided with knowledge about the exact coordinated transmission (from which points, with what transmission weights etc). This information can be used for received signal processing at the terminal side, but comes at a cost of increased downlink overhead.

For the uplink, coordinated multipoint reception is mainly a question of applying the relevant signal processing at the receiver. In many respects, this is similar to macro diversity, used already today in many cellular systems.

D. *Relays and Repeaters*

Another possibility for, from a link-budget perspective, providing a denser infrastructure is to deploy different types of relaying solutions. In essence, the intention is to reduce the transmitter-to-receiver distance, thereby allowing for higher data rates. Depending on the scheme applied, different types of relaying solutions can be envisioned.

Repeaters simply amplify and forward the received analog signals and are used already today for handling coverage holes. Traditionally, once installed, repeaters continuously forwards the received signal regardless of whether there is a terminal in its coverage area or not. Such repeaters are invisible to both the terminal and the base station. However, more advanced repeater structures ("L1 relays") can be considered, e.g. schemes where the network can control the transmission power of the repeater and, for example, activate the repeater only when users are present in the area handled by the repeater in order to increase the supported data rates in the area. Additional measurement reports from the terminals can also be considered as means to guide the network in which repeaters to switch on. However, scheduling and retransmission control always reside in the base station and repeaters are therefore transparent from a mobility perspective.

The intermediate node may also decode and re-encode any received data prior to forwarding it to the served users. This is often referred to as *decode-and-forward* relaying. As the intermediate node decodes and re-encodes received data blocks a significant delay is introduced, longer than the LTE subframe duration of 1 ms. However, no noise is forwarded by the relay node and rate adaptation may be performed individually for each link. As for repeaters, many different options exist depending on supported features (e.g. support of more than two hops, support of mesh structures) but on a high-level two different classes may be distinguished, based on whether forwarding is performed on layer 2 (often denoted L2 relaying) or on layer 3 (often denoted L3 relaying or *self backhauling*). Although very similar in their basic characteristics (e.g. both introduces delays, neither suffers from noise amplification) the self-backhauling solution does not require any new nodes, protocols or interfaces to be standardized as the existing solutions are reused and may therefore preferable over their L2 counterpart.

IV. PERFORMANCE ASSESSMENT

To assess the potential of some of the LTE-Advanced technologies, simple system level performance evaluations have been carried out. The downlink user data rate and capacity achievable in systems using CoMP (approach B) are compared to those of a conventional system. The number of sites coordinated by one eNodeB is set to 7 or 19, and the area over which transmissions are coordinated by one eNodeB is referred to as a "CoMP cell". Different CoMP cells act independently from each other; coordination is only done between sites within a CoMP cell. For downlink transmissions, a combination of linear zero-forcing beam forming and non-linear dirty-paper coding [8] is used. Uplink transmissions are scheduled independently between terminals and receiver processing in the form of interference suppression and cancellation is used. Finally, as the performance of CoMP systems on the downlink is heavily dependent on accurate channel estimates available at the coordinating eNodeB, different levels of channel estimation accuracy at the eNodeB are studied.

A. *Models and Assumptions*

Models and assumptions, of which a subset is listed in Table 1, are aligned with 3GPP simulation case 1 [6], including use of the Spatial Channel Model (SCM). A series of snapshot simulations have been used. In each iteration of the simulation, terminals are randomly positioned in the system area, and the radio channel between each base station and terminal antenna pair is calculated according to the propagation and fading models. To study different levels of system load, terminals are randomly selected to be transmitting (or receiving) with an activity factor *f* ranging from 10% to 100%. In active cells transmitting (or receiving) users are selected independently of channel quality.

For the downlink, the zero-forcing weights are computed based on estimated channel values that are generated by adding a random error to the actual channel values. The channel estimation error for each channel is assumed to be zero-mean complex Gaussian with variance Q_0/P, where Q_0 is a constant and P is used to vary the channel estimation accuracy. Based on the transmit weights, the channel realizations, the active interferers, and a simple model for dirty-paper encoding with estimated channels [9], a signal-to-interference and noise ratio (SINR) is calculated for each link assuming an MMSE receive model. Next, an effective SNR is calculated per downlink resource block.

For the uplink, based on the channel realizations, the active interferers, and a simple model for a successive interference canceling receiver with MMSE, an SINR is calculated for each link. Finally, an effective SNR is calculated per uplink resource block.

The effective SNRs in uplink and downlink are mapped to active radio link data rates R_u for each active user u using the mutual information model of [7]. Note that R_u is the data rate that user u gets when scheduled. Active base stations and users differ between iterations, and statistics are collected over a large number of iterations. For each activity factor, the served traffic per cell $T(f)$ is calculated as the sum of the active radio link data rates for the active users

$$T(f) = \sum_{u=1}^{U(f)} R_u / N_{\text{cell}} \tag{2}$$

where $U(f)$ is the total number of active users for activity factor f, and. N_{cell} is the total number of cells in the system (21 or 57 times the number of CoMP cells). This assumes that user are scheduled an equal amount of time. The mean and the 10th percentile of the active radio link bitrate are used as measures of average and cell-edge user quality respectively. Note that as the activity factor increases, individual user data rates decrease because of increased interference and thereby decreased SINR. The served traffic however increases as the number of active users increase.

B. *Numerical Results*

Fig. 4 and Fig. 5 show the resulting cell-edge and average active radio link bitrate (R) as a function of the served traffic per cell (*T*) for the downlink. It is seen that the CoMP system yields significant performance gains. As expected the gain is larger for the system with more coordinated cells. The loss due to using erroneous channel values at the transmitter is evident, but a majority of the gain remains.

TABLE I. SIMULATION PARAMETERS

Traffic Models	
User distribution	Uniform
Data generation	On-off with activity factor *f* ; 10, 25, 50, 100%
Radio Network Models	
Distance attenuation	L = 35.3+37.6·log(d), d = distance in meters
Shadow fading	Log-normal, 8 dB standard deviation
Multipath fading	SCM, suburban macro
Cell layout	Hexagonal grid, 3-sector sites
Cell radius	334m (1000m inter-site distance)
System Models	
Spectrum allocation	5MHz bandwidth at 2GHz
Max antenna gain	15dBi
Modulation and coding	QPSK & 16QAM, 3GPP turbo codes
Overhead	28% for reference signals and L1/L2 control channels (10 symbols per TTI for data)
UE antennas	2 per UE with half-wavelength spacing
Network antennas	2 per cell with 10-wavelength spacing

Fig. 6 and Fig. 7 show the resulting cell-edge and average active radio link bit rate (*R*) as a function of the served traffic per cell (*T*) for the uplink. It is seen that the CoMP system yields significant performance gains, and the gains are larger for the system with more coordinated cells. Recall that the transmitted signals in uplink CoMP are generated independently of the channel realizations; hence, from a coordination perspective there is no need to consider channel estimation errors at the transmitter for the uplink.

These results are indeed very promising. Note however that several ideal assumption have been made that are challenging to solve, foremost including feedback of estimates of downlink channels (encoding and transmitting with low latency).

V. CONCLUSION

This paper has provided a high-level overview of some technology components currently considered for the evolution of LTE including complete fulfillment of the IMT-Advanced requirements. These technology components include extended spectrum flexibility, multi-antenna solutions, coordinated multi-point transmission/reception, and the use of advanced repeaters/relaying.

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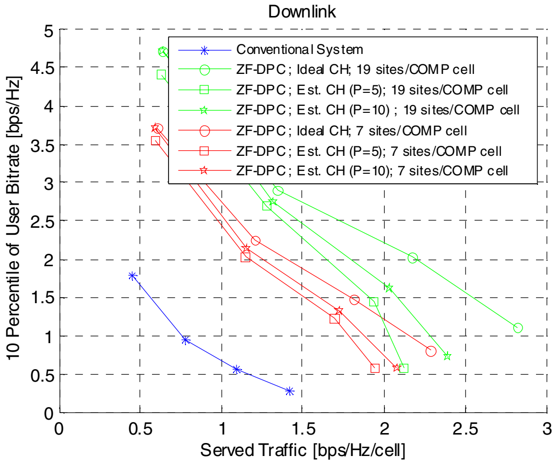

Figure 4. Downlink cell-edge bitrate as a function of traffic load.

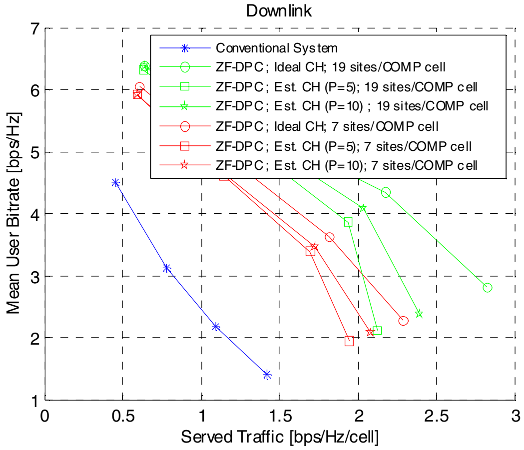

Figure 5. Downlink mean bitrate as a function of traffic load

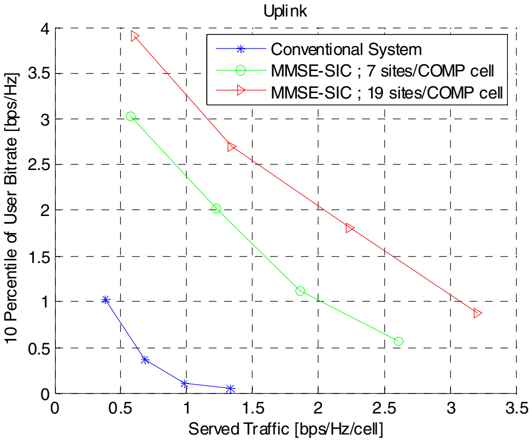

Figure 6. Uplink cell-edge bitrate as a function of traffic load

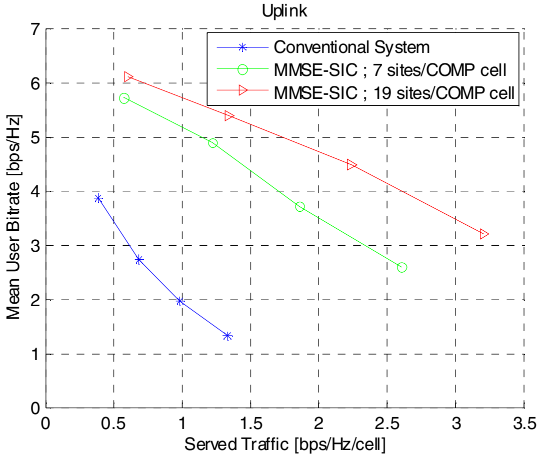

Figure 7. Uplink mean data rate as a function of traffic load.