LTE Advanced – A Further Evolutionary Step for Next Generation Mobile Networks

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Abstract. *The World Radio Conference in 2007 identified additional spectrum for IMT-2000 and IMT-Advanced systems. That's why also 3GPP has started a feasibility study for LTE-Advanced techniques to continuously evolve LTE technology.*

LTE-Advanced is expected to enable download peak rates over 1Gbps at 100MHz bandwidth and in the upload peak rates over 0.5Gbps. Novel techniques on radio interface are going to be analyzed especially to improve spectral efficiency and cell edge performance. Advanced Antenna systems, Multi-User and Multi-Cell Multiple-Input Multiple-Output, Coordinated Multi-Point (CoMP) transmission schemes for interference reduction, Cooperative Relaying are some of potential features to enhance the Next Generation Mobile Network.

Keywords

Evolved Universal Terrestrial Radio Access, LTE-Advanced, Coordinated Multi-Point Transmission, Multi-User MIMO, Carrier Aggregation, Beamforming, Relaying, Multilayer networks.

1. Introduction

Evolved Universal Terrestrial Radio Access (E-UTRA) network is considered to be one of the potential next generation mobile technologies. The E-UTRA is targeted by 3GPP as an evolutionary path from the GSM and UMTS. That's why E-UTRA is also called as Long Term Evolution (LTE) of 3GPP.

E-UTRA is Orthogonal Frequency Division Multiplex Access (OFDMA) based technology with peak data rates exceeding 300Mbps in the downlink, Single Carrier – Frequency Division Multiplex Access (SC-FDMA) with more than 75 Mbps in the uplink and flexibility to support different frequency bands and channel bandwidths. E-UTRA offers excellent performance thanks to the new radio techniques (frequency selective scheduler, open- and closed-loop multiple-input multiple-output transmission, adaptive modulation and coding with short transmission time interval, Inter-Cell Interference Coordination (ICIC), etc.) and all-IP Packet only Core Network known as the Evolved Packet Core (EPC). Even there is quite significant performance enhancement in comparison with previous technologies LTE is still not considered as 4G system.

The formal definition of 4G wireless system is being developed by ITU-R. The World Radio Conference in 2007 identified additional spectrum for IMT-2000 and IMT-Advanced systems. That's why also 3GPP has started a feasibility study for LTE-Advanced techniques to continuously evolve LTE technology.

In September 2009 the 3GPP Partners made a formal submission to the ITU proposing that LTE Release 10 & beyond (LTE-Advanced) be evaluated as a candidate for IMT-Advanced [1].

2. LTE-Advanced

LTE-Advanced is expected to enable download peak rates over 1Gbps at 100 MHz bandwidth and in the uplink peak rates greater than 500 Mbps. LTE-Advanced will utilise the diverse spectrum bands already applicable for LTE as well as future IMT-Advanced bands.

Further improvement of the spectral efficiency in the uplink and downlink is targeted, especially when serving users at the cell edge. One key objective is to seek mitigation for the intercell interference that constrains spectrum efficiency and restricts the data rate of cell edge users. LTE-Advanced also targets faster switching between radio resource states and further improvement of the latency figures.

At the same time the cost per bit should be reduced e.g., by addressing the backhaul challenge, enhancing self organizing network functionality, defining additional multi-vendor interfaces, and allowing for innovative deployment concepts such as relaying and multi-cell cooperative techniques.

LTE-Advanced is an evolution of the LTE with a strong demand for full backward compatibility. Some degree of incompatibility however may be considered for features where the advantage is truly compelling.

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2.1 Carrier Aggregation

One way to reach peak performance requirements is Carrier Aggregation, which by no means is a new idea. Extension up to 100MHz channel bandwidth in multiple bands is considered. Main implementation issue with Carrier Aggregation is largely increased complexity especially on terminal side. It should also be noted that wider channels offer a better trunking efficiency but do not increase spectral efficiency.

Carrier aggregation shall support both contiguous and non-contiguous spectrum with single carrier limit up to 110 Resource Blocks (1RB = 180kHz). The main reason is backward compatibility with Rel-8 terminals (LTE). It should also be possible to allocate different numbers of carriers for uplink and downlink, which will increase flexibility of network dimensioning in case of asymmetric traffic.

It is obvious that non-contiguous carrier aggregation from different bands in multi-transceiver mobile devices is the most relevant approach. However this is a challenge especially for channel estimation, output power stability, signal quality (Error Vector Magnitude), spurious emissions, receiver selectivity and sensitivity, intermodulation performance, etc. Each wide-band carrier presents an RF propagation channel with different characteristics. If the frequency bands are quite far apart for downlink and uplink transmission the pathloss is not reciprocal. It means estimations (e.g., for UL power control, ICIC or RSRP for handover) cannot be used in the same way as in Rel-8.

LTE-Advanced extends the uplink transmission scheme by allowing clustered SC-FDMA, i.e. the uplink transmission is not anymore restricted to the use of consecutive subcarriers, but clusters of subcarriers may be allocated. This allows for more flexible frequency selective scheduling in the uplink and consequently will increase the system performance.

2.2 Higher order MIMO and Beamforming

LTE Rel-8 supports multiple-input multiple-output (MIMO) transmission schemes in both downlink and uplink. In downlink direction up to four transmit antennas may be used whereas the maximum number of codewords is two, irrespective of the number of antennas. Spatial division multiplexing (SDM) of multiple modulation symbol streams to both a single UE using the same time-frequency resource, also referred to as Single-User MIMO (SU-MIMO) and to different UEs using the same time-frequency resource, also referred to as Multi-User MIMO (MU-MIMO) are supported. In the uplink direction only MU-MIMO is used, i.e. there is only one modulated symbol stream per UE to be received by the NodeB, whereas multiple UEs may transmit on the same time-frequency resource.

LTE-Advanced aims to increase and support a downlink peak spectrum efficiency of more than 15bps/Hz for eight antennas (MIMO 8x8) and an uplink spectrum efficiency above 7bps/Hz with four antennas (MIMO 4x4).

The potential gain from MIMO and antenna beamforming is always a function of the number of antennas (columns). Higher order MIMO can benefit especially on peak and average data rates while Beamforming brings the most advantage on the cell edge. The performance is strongly dependent on the instantaneous correlation of each radio channel. Especially channel estimation in case of FDD is very challenging and feedback from the UEs is required. This is increasing the computational complexity and the overall overhead of the system.

Multi beam processing may significantly enhance the performance in interference limited cells. Improvements can be achieved in terms of inter-cell interference, intra-cell interference, uplink imbalance and enhancements in the presence of multipath.

It is proven theoretically and also in the field that single-layer beamforming with eight columns can bring significant gains. Especially dual-layer beamforming is proposed to support enhanced beamforming transmission achieving spatial multiplexing gain and increase system capability of LTE-Advanced [14]. The spectrum efficiency depends on the proper reference signal design, multiplexing methods and reference signal location. The dual-layer transmission requires the orthogonality of two layers in both data transmission and channel estimation.

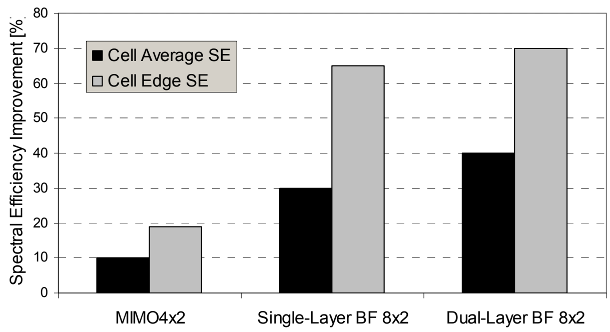

Fig. 1. Average and Cell Edge spectral efficiency improvement in comparison with conventional MIMO2x2 for the 3GPP Urban Macro case 1.

Simulation results on Fig. 1 demonstrate average and cell edge spectral efficiency improvement for MIMO4x2, Single-Layer Beamforming 8x2 and Dual-Layer Beamforming 8x2 in comparison with conventional MIMO2x2. It is obvious that beamforming has much better performance especially in poor radio channel condition on cell edge (~65%). Average cell capacity improvement is about 30%.

2.3 Coordinated Multipoint Transmission and Reception

Coordinated multipoint (CoMP) transmission and reception techniques are based on cooperation between different base stations using fast backhaul network in order to significantly improve the interference situation and thus the overall system performance. In the downlink, this principle could be used for realizing joint transmission, for example, where one UE is simultaneously served by multiple base stations. This way, not only the signal strength of the signal intended for the respective UE may be considerably improved, but at the same time also the interference originating from transmissions to other UEs can be reduced, thus actually leading to a two-fold performance gain. Since the exclusive assignment of certain radio resources in multiple cooperating cells to one particular UE would come along with a loss of spectral efficiency, however, in general multiple UEs should be jointly served by the set of cooperating cells at the same time, for example by employing well-known multi-user MIMO transmission schemes across the various cells [2][3].

Since multi-cell channel state information of the various UEs is required at the base station side in order to perform joint transmission, the uplink signaling load is significantly increased compared to conventional systems without cooperation. In order to reduce the uplink feedback requirements, different base stations may also cooperate in a somewhat looser way without the need for explicit multi-cell channel state information at the BS side by only coordinating the resource allocation and/or the choice of appropriate MIMO precoders across various cells while the actual data is still transmitted by a single base station only [12]. By doing so, in particular situations where neighboring base stations transmit at the same time and on the same frequency resources to UEs who are rather close together and hence would experience relatively high interference from the respective other cell can be almost completely avoided.

In the uplink, in contrast, cooperating base stations could exchange appropriate information in order to improve the signal detection. Similar to joint transmission in the downlink, a two-fold gain can be obtained this way. On one hand we have an effective increase of the number of receive antennas and hence can benefit from higher spatial diversity while on the other hand signals which represent interference in conventional systems are now treated as useful signals and contribute to an increased detection probability.

Some recent theoretical results revealed the fundamental potential of CoMP techniques and it has been shown that in principle tremendous performance gains may be realized this way [4][5]. In a practical system like the 3GPP Long Term Evolution, however, the achievable gains generally are expected to be well below the theoretical limits, yet significant. This is due to various practical issues like restricted subsets of base stations that could cooperate, as they should be located in close geographical vicinity. Another example is channel estimation errors and the general difficulty to perform accurate multi-cell channel estimation, as well as synchronization challenges. In addition to that, efficient joint transmission in the downlink, for example, generally requires accurate (multi-cell) channel state information at the base station side. In case of the common LTE FDD mode, these channels naturally have to be estimated by the UEs, thus leading to a rather high computational effort as well as a high signaling load in the uplink. Moreover, depending on what information is exchanged between cooperating base stations, a rather high backhaul load may occur, which may reach data rates in the order of several Gbit/s in case of joint detection in the uplink, for example. While it should be still feasible to cope with this traffic if the base stations are interconnected by means of optical fibers, things are already getting more challenging in case of microwave links or copper lines. Apart from that, the cooperation stage generally adds an additional delay to the data processing and thus increases the overall latency. Therefore rather promising approach for the short-term is to support only cooperation between the various sectors of the same site, but not between different sites. This way, many of the general problems outlined above can easily be overcome because all base stations of the same site usually are integrated into the same physical device and no transmission via the backhaul network is necessary [6].

In LTE-Advanced, different base stations generally may cooperate with each other using the X2 interface [9]. This interface, however, is only a logical one and therefore it is not assured that there is always a direct link between two cooperating sites. For that reason, also the network structure may have to be adjusted by operators in order to enable the efficient application of CoMP schemes in practice. In the uplink, the support of CoMP techniques is commonly considered as an implementation-specific issue and for many schemes it is basically sufficient to standardize only the data exchanged via the X2-interface. In the downlink, in contrast, the feedback signaling in case of FDD has to be extended and the sounding reference signals may have to be adjusted in order to enable efficient multi-cell channel estimation. Besides, for joint transmission also new precoding schemes have to be defined and means for signaling the used precoders to the corresponding UEs [7].

In order to provide an idea of what gains may be achieved with CoMP techniques in an LTE-Advanced system, Fig. 2 shows some basic performance results for the uplink obtained from detailed system-level simulations. In this regard, we particularly compare the performance of a conventional LTE Rel-8 system to the one that may be achieved with joint processing in case that each sector is cooperating with its six direct neighbor sectors. As a first approach, we consider classical joint detection in the sense that the cooperating sectors simply quantize the received signals and signal these signals along with corresponding channel state information to their respective cooperating base stations, so that effectively a larger receive antenna array is created. As another alternative, we consider a distributed successive interference cancelation (SIC) scheme, which works similar to SIC detection for conventional MIMO systems [11]. In this regard, the base stations first of all try to detect the UEs transmitting in their own sector without any support from other base stations. In case that some UEs have been detected, the data transmitted by them is signaled to all cooperating BSs, which—provided that they have accurate multi-cell channel state information—can then accurately reconstruct the interference caused by these UEs and subtract it from their own received signals. Hence, the probability that the UEs transmitting in the respective cells can be decoded consequently can be improved. This process may then be repeated in an iterative fashion until either no further UE can be decoded or until a predefined maximum number of iterations has been reached.

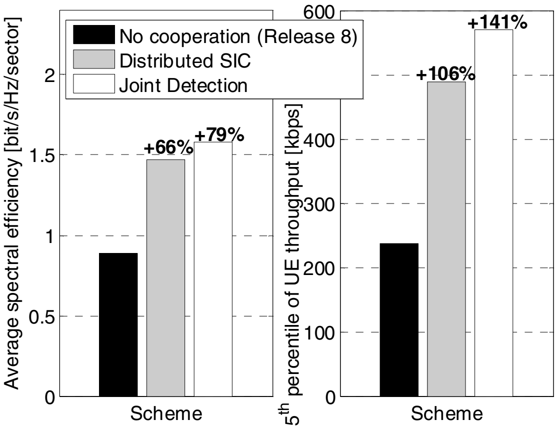

Fig. 2. Average spectral efficiency and cell-edge throughput for the LTE uplink with distributed SIC and joint detection for the 3GPP Urban Macro case 1, assuming 6 cooperating sectors per base station. The given percentages denote the relative performance gains compared to the reference Release 8 setup without any cooperation.

For the particular results shown in Fig. 2, always the simulation assumptions compiled in [9] have been used with the additional assumption of perfect channel estimation. As can be seen, with both approaches significant performance gains can be achieved compared to the reference LTE Rel-8 system, where the gains with joint detection are even slightly higher than those with distributed SIC. Intuitively this is quite clear since in the latter case the gains are only due to the cancelation of interference whereas in the other case also the effective received signal strength of the desired signal can be improved. However, it should be noted that the backhaul load as well as the latency requirement of the two different approaches actually are quite different. While with the distributed SIC scheme primarily only bits transmitted by certain UEs are exchanged, joint detection requires the exchange of the quantized received signals, which generally may result—depending on the quantization granularity—in orders of magnitudes higher backhaul loads. By contrast, the latency in case of distributed SIC is considerably higher than in case of joint detection since with each iteration an additional delay is introduced due to the information exchange as well as due to data processing. For the particular simulation results shown in Fig. 2, the average backhaul load per base station that we have determined was in the order of 50 MBit/s for distributed SIC and up to several GBit/s for joint detection. However, it should be further noted that for both cases the backhaul load may be further reduced with only minor performance losses, for example by exchanging only information for a certain UE on the backhaul network if the interference level caused by this UE is above a certain threshold value. Some more detailed results on such approaches can be found in [10], for example.

2.4 Relays

Relaying is just another method how to improve coverage in difficult conditions. More advanced relays can in principle decode transmissions before retransmitting and operate on Layer 2 or Layer 3. This opens the possibility to selectively forward the traffic to the local user and thus minimize the interference.

LTE-Advanced extends coverage options for in-band and out-band relaying. The Relay Node (RN) is connected to a donor cell (eNodeB) via the Un interface and Ue is connected to the RN via Uu interface. RN is separate cell with own physical cell ID and synchronization channels, reference symbols, etc. This means all Uu control plane and user plane protocols are terminated in the RN. Resource partitioning with time division multiplex for Uu and Un (only one active in any time) is introduced.

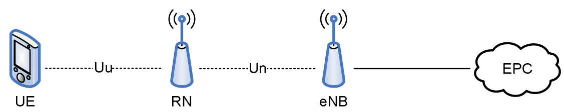

Fig. 3. Relaying Architecture.

In case of in-band relaying there is a need to control the RN and eNodeB transmissions in order to avoid interference. The challenge is again backward compatibility of such a solution to conventional Rel-8 terminals. One of the options could be "gaps" created by configuring MBSFN subframes in the relay-to-UE transmission.

2.5 Multilayer Network

Since the data traffic is going to increase exponentially during the next few years, macro layer capacity does not seem to be sufficient even if LTE-Advanced techniques deliver significant performance improvements on the air interface. Due to this fact multilayer networks are considered as an essential deployment scenario.

Macro cell splitting or higher order sectorization is still the most effective method for capacity extension. However macro site density is reaching a practical limit. That's why Pico and Femto cells are considered as the only option how to increase network capacity, especially for highly loaded area (hot spots). The complexity of such heterogeneous networks is much higher and there are some key challenges for realization. Especially interference avoidance and cancelation between network layers, inband/outband backhauling, traffic asymmetry, plug-and-play features (self organizing network), etc. Heterogeneous networks require new features to improve the LTE-Advanced system performance.

3. A Further Evolutionary Step

There are more features and enhancements to be studied and analyzed for Next Generation Mobile Networks. Nevertheless further evolutionary steps significantly depend on the overall complexity, potential improvements, cost drivers, practical limitations, etc. For example CoMP opens new opportunities for a lot of coordinated features. However each feature increases backhaul requirements, which seem to be technically and economically challenging at this moment. That's why it is essential that all enhancements need to be assessed also in from an economical point of view before being implemented in a real-world system.

References

[1] 3GPP TR36.912, v9.1.0 – *Feasibility Study For Further Advancements for E-UTRA (LTE-Advanced)* – Release 9.

[2] GESBERT, D., KOUNTOURIS, M., HEATH, R. W. Jr., CHAE, C.-B., SALZER, T. Shifting the MIMO paradigm: from single user to multiuser communications. *IEEE Signal Proc. Mag.*, vol. 24, no. 5, Oct. 2007, pp. 36 – 46.

[3] SPENCER, Q. H., PEEL, C. B., SWINDLEHURST, A. L., HAARDT, M. An introduction to the multi-user MIMO downlink. IEEE Commun. Mag., vol. 42, no. 10, Oct. 2004, pp. 60 – 67.

[4] KARAKAYALI, M. K., FOSCHINI, G. J., VALENZUELA, R. A. Network coordination for spectrally efficient communications in cellular systems. *IEEE Wireless Commun.*, vol. 13, no. 4, Aug. 2006, pp. 56 – 61.

[5] VENKATESAN, S. Coordinating base stations for greater uplink spectral efficiency in a cellular network. *Proc. IEEE Int. Symp. Pers., Indoor and Mobile Radio Commun.*, Sep. 2007.

[6] MULLER, A., FRANK, P., SPEIDEL, J. Performance of the LTE uplink with intra-site joint detection and joint link adaptation. *Proc. IEEE Veh. Technol. Conf,.* May 2010.

[7] 3GPP TR 36.814, v1.5.0, *Further advancements of E-UTRA – physical layer aspects*, Nov. 2009.

[8] 3GPP TR 25.814 v7.1.0, *Physical layer aspects for evolved universal terrestrial radio access (UTRA)*, Sep. 2006.

[9] 3GPP TS 36.420, v9.0.0, *Evolved universal terrestrial radio access network (E-UTRAN): X2 general aspects and principles*, Dec. 2009.

[10] FRANK, P., MULLER, A., SPEIDEL, J. *Inter-site joint detection with reduced backhaul capacity requirements for the 3GPP LTE uplink*. Submitted to *IEEE Veh. Technol. Conf.*, Sep. 2010.

[11] FOSCHINI, J. *et al*. Simplified processing for high spectral efficiency wireless communication employing multi-element arrays. *IEEE J. Select. Areas Commun.*, vol. 17, no. 11, Nov. 1999, pp. 1841 – 1852.

[12] LIU, L., ZHANG, J., YU, J.-C., LEE, J. Inter-cell interference coordination through limited feedback. *International Journal of Digital Multimedia Broadcasting*, vol. 2010, Article ID 134919.

[13] Agilent Technoloies Publication, RUMNEY, M. (ed.). *LTE and the Evolution to 4G Wireless*. ISBN 978-988-17935-1-5.

[14] LIU, Y. Research on FDM Based DRS Pattern for Dual-layer Beamforming in LTE System. In *International Conference on Wireless Networks and Information Systems*. pp. 3 – 6, 2009.