



LTE Advanced: Heterogeneous Networks



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Table of Contents

Executive Summary 1

[1] Introduction 2

[2] Heterogeneous Networks 3

 2.1 Traditional Network Deployment Approach..... 3

 2.2 An Alternate Approach Using Heterogeneous Network..... 3

[3] Key Design Features 4

 3.1 Range expansion..... 4

 3.2 Advanced Interference Management 7

 3.2.1 Inter-cell Interference Coordination (ICIC) 7

 3.2.2 Slowly-Adaptive Interference Management 9

[4] Technology Performance 9

[5] Conclusion 12

[6] Glossary 13

[7] References 13

Executive Summary

Long-Term Evolution (LTE) allows operators to use new and wider spectrum and complements 3G networks with higher data rates, lower latency and a flat, IP-based architecture. To further improve the broadband user experience in a ubiquitous and cost-effective manner, 3GPP has been working on various aspects of the LTE Advanced standard.

Since radio link performance is fast approaching theoretical limits with 3G Enhancements and LTE, the next performance leap in wireless networks will come from an evolved network *topology*. The concept of LTE Advanced-based Heterogeneous Networks is about improving spectral efficiency per unit area. Using a mix of macro, pico, femto and relay base stations, heterogeneous networks enable flexible and low-cost deployments and provide a uniform broadband experience to users anywhere in the network.

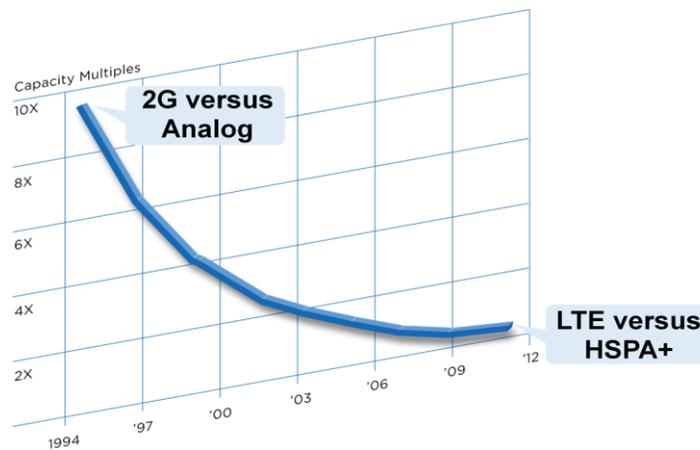
This paper discusses the need for an alternative deployment model and topology using heterogeneous networks. To enhance the performance of these networks, advanced techniques are described, which are needed to manage and control interference and deliver the full benefits of such networks.

Range expansion allows more user terminals to benefit directly from low-power base stations such as picos, femtos and relays. Adaptive inter-cell interference coordination provides *smart* resource allocation amongst interfering cells and improves inter-cell “fairness” in a heterogeneous network. In addition, the performance gains possible via heterogeneous networks are shown using a macro/pico network example.

[1] Introduction

Developed by 3GPP, LTE is the leading OFDMA wireless mobile broadband technology. LTE offers high spectral efficiency, low latency and high peak data rates. LTE leverages the economies of scale of 3G, as well as the global ecosystem of infrastructure and device vendors, to provide the highest performance in a cost effective manner.

The LTE standard was first published in March of 2009 as part of the 3GPP Release 8 specifications. Comparing the performance of 3G and its evolution to LTE, LTE does not offer anything unique to improve spectral efficiency, i.e. bps/Hz. However, LTE significantly improves system performance by using wider bandwidths where spectrum is available.



[Figure 1]
Improvements in spectral efficiency are approaching theoretical limits

To achieve performance improvements in LTE Advanced, the 3GPP has been working on various aspects of LTE including higher order MIMO (multiple antennas), carrier aggregation (multiple component carriers), and heterogeneous networks (picos, femtos and relays). Since improvements in spectral efficiency per link are approaching theoretical limits with 3G and LTE, as shown in Figure 1, the next generation of technology is about improving spectral efficiency per unit area.

In other words, LTE Advanced needs to provide a uniform user experience to users *anywhere* inside a cell — by changing the topology of traditional networks. The key

Topology will provide the next performance leap for wireless networks beyond radio link improvements.

benefits of LTE Advanced in heterogeneous network deployments are highlighted in the discussion that follows.

[2] Heterogeneous Networks

2.1 Traditional Network Deployment Approach

Current wireless cellular networks are typically deployed as homogeneous networks using a macro-centric planning process. A *homogeneous* cellular system is a network of base stations in a planned layout and a collection of user terminals, in which all the base stations have similar transmit power levels, antenna patterns, receiver noise floors and similar backhaul connectivity to the (packet) data network. Moreover, all base stations offer unrestricted access to user terminals in the network, and serve roughly the same number of user terminals, all of which carry similar data flows with similar QoS requirements.

The locations of the macro base stations are carefully chosen through network planning, and the base station settings are properly configured to maximize the coverage and control the interference between base stations. As the traffic demand grows and the RF environment changes, the network relies on cell splitting or additional carriers to overcome capacity and link budget limitations and maintain uniform user experience. However, this deployment process is complex and iterative. Moreover, site acquisition for macro base stations with towers becomes more difficult in dense urban areas. A more flexible deployment model is needed for operators to improve broadband user experience in a ubiquitous and cost-effective way.

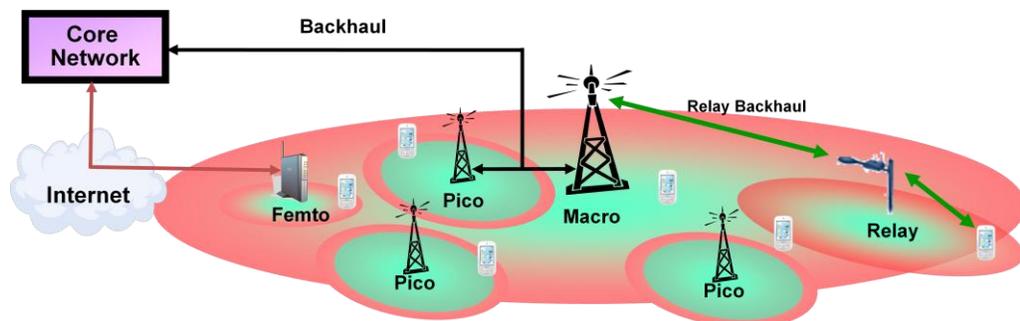
2.2 An Alternate Approach Using Heterogeneous Network

Wireless cellular systems have evolved to the point where an isolated system (with just one base station) achieves near optimal performance, as determined by information theoretic capacity limits. Future gains of wireless networks will be obtained more from advanced network topology, which will bring the network closer to the mobile users. *Heterogeneous* networks, utilizing a diverse set of base stations, can be deployed to improve spectral efficiency per unit area.

Consider the heterogeneous cellular system depicted in Figure 2. This cellular system consists of regular (planned) placement of macro base stations that typically transmit at high power level (~5W - 40W), overlaid with several pico base stations, femto base stations and relay base stations, which transmit at substantially lower power levels (~100mW - 2W) and are typically deployed in a relatively unplanned manner.

Heterogeneous network enables flexible and low-cost deployment using mix of macro, pico, femto, and relay base-stations.

The low-power base stations can be deployed to eliminate coverage holes in the macro-only system and improve capacity in hot spots. While the placement of macro base stations in a cellular network is generally based on careful network planning, the placement of pico/relay base stations may be more or less ad hoc, based on just a rough knowledge of coverage issues and traffic density (e.g. hot spots) in the network. Due to their lower transmit power and smaller physical size, pico/femto/relay base stations can offer flexible site acquisitions. Relay base stations offer additional flexibility in backhaul where wireline backhaul is unavailable or not economical.



[Figure 2]

Heterogeneous Network utilizing mix of macro, pico, femto and relay base stations

In a homogeneous network, each mobile terminal is served by the base stations with the strongest signal strength, while the unwanted signals received from other base stations are usually treated as interference. In a heterogeneous network, such principles can lead to significantly suboptimal performance. In such systems, smarter resource coordination among base stations, better server selection strategies and more advanced techniques for efficient interference management can provide substantial gains in throughput and user experience as compared to a conventional approach of deploying cellular network infrastructure.

[3] Key Design Features

3.1 Range expansion

A pico base station is characterized by a substantially lower transmit power as compared to a macro base station, and a mostly ad hoc placement in the network. Because of unplanned deployment, most cellular networks with pico base stations can be expected to have large areas with low signal-to-interference conditions, resulting in a challenging RF environment for control channel transmissions to users on the cell

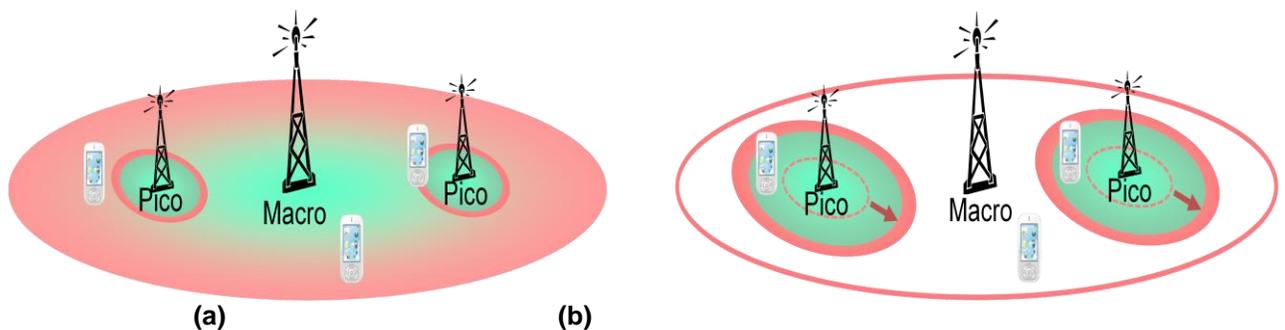
edge. More importantly, the potentially large disparity (e.g. 20dB) between the transmit power levels of macro and pico base stations implies that in a mixed macro/pico deployment, the downlink coverage of a pico base station is much smaller than that of a macro base station.

This is not the case for the uplink, where the strength of the signal received from a user terminal depends on the terminal transmit power, which is the same for all uplinks from the terminal to different base stations. Hence, the uplink coverage of all the base stations is similar and the uplink handover boundaries are determined based on channel gains. This can create a mismatch between downlink and uplink handover boundaries, and make the base station-to-user terminal association (or server selection) more difficult in heterogeneous networks, compared to homogenous networks, where downlink and uplink handover boundaries are more closely matched.

If server selection is predominantly based on downlink signal strength, as in LTE Rel-8, the usefulness of pico base stations will be greatly diminished. In this scenario, the larger coverage of high-power base stations limits the benefits of cell splitting by attracting most user terminals towards macro base stations based on signal strength without having enough macro base station resources to efficiently serve these user terminals. And lower power base-stations may not be serving *any* user terminals.

Even if all the low-power base stations can use available spectrum to serve at least one user terminal, the difference between the loadings of different base stations can result in an unfair distribution of data rates and uneven user experiences among the user terminals in the network. Therefore, from the point of view of network capacity, it is desirable to balance the load between macro and pico base stations by expanding the coverage of pico base stations and subsequently increase cell splitting gains. We will refer to this concept as *range expansion*, which is illustrated in Figure 3.

Range extension allows more user terminals to benefit directly from low-power base-stations such as picos, femtos, and relays, and maximizes the user experience.

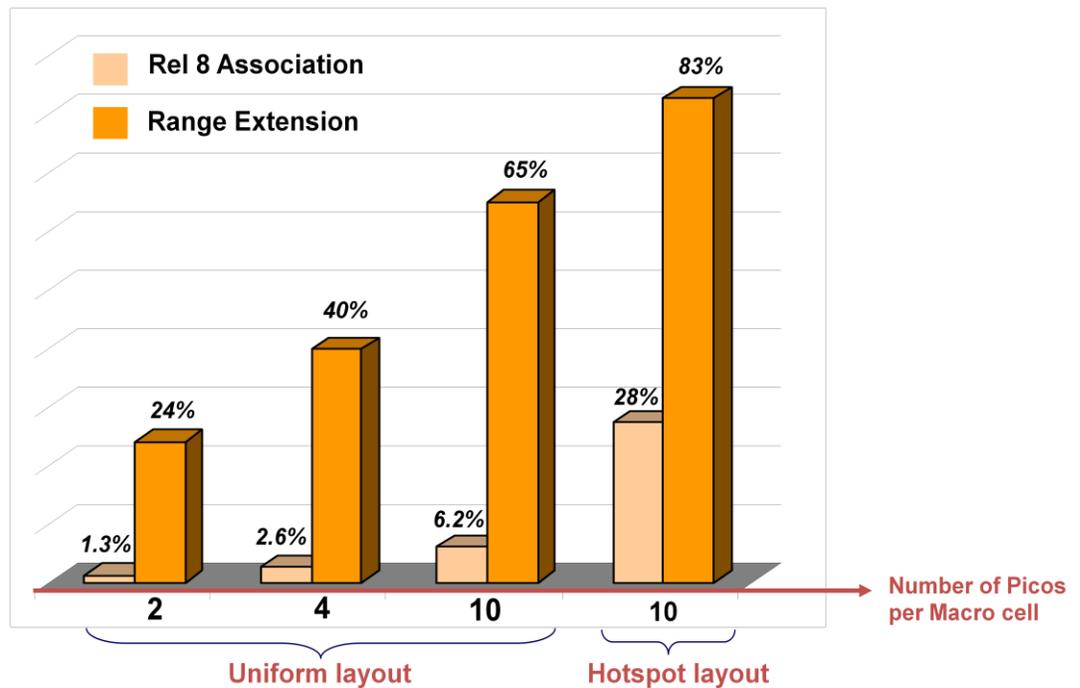


[Figure 3] (a) Limited footprint of picos due to strong macro signal;
(b) Increased footprint of picos with range expansion.

A simple example of two categories of macro and pico base stations can be used to demonstrate potential gains from range expansion. [Figure 4 shows the user association statistics with and without range expansion for the mixed macro and pico deployment (configuration 1 in [2]).

The range expansion here is achieved by performing base station to terminal association based on path loss (associating with the base station with the *minimum path loss* rather than the base station with the *maximum downlink signal strength*) and a fixed partitioning of resources equally between the macro and pico base stations.

As seen in the figure, range expansion allows many more users to associate with the pico base stations and enables more equitable distribution of airlink resources to each user. The effect is even more pronounced in hotspot layouts (configuration 4 in [2]) where users are clustered around pico base stations. Capacity gains can be achieved through sharing of the resources allocated for *low-power* base stations, while sufficient coverage is provided by *high-power* base stations on the resources that are allocated to them.



[Figure 4] Pico-cell user association statistics with and without range expansion

3.2 Advanced Interference Management

3.2.1 Inter-cell Interference Coordination (ICIC)

In a *heterogeneous* network with range expansion, in order for a user terminal to obtain service from a low-power base station in the presence of macro base stations with stronger downlink signal strength, the pico base station needs to perform both control channel and data channel interference coordination with the dominant macro interferers and the user terminals need to support advanced receivers for interference cancellation. In the case of femto base stations, only the owner or subscribers of the femto base-station may be allowed to access the femto base stations.

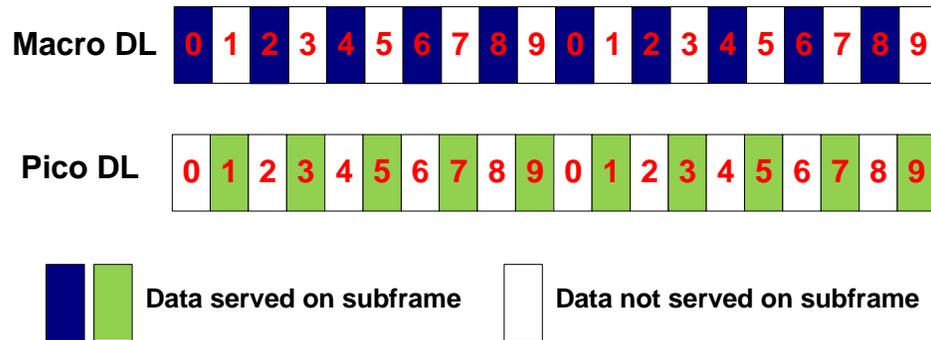
For user terminals that are close to these femto base stations but yet barred from accessing them, the interference caused by the femto base stations to the user terminals can be particularly severe, making it difficult to establish a reliable downlink communication to these user terminals. Hence, as opposed to homogeneous networks, where resource reuse one (with minor adjustments) is a good transmission scheme, femto networks necessitate more coordination via resource partitioning across base stations to manage inter-cell interference.

As a result, *Inter-cell Interference Coordination* (ICIC) is critical to heterogeneous network deployment. A basic ICIC technique involves resource coordination amongst interfering base stations, where an interfering base station gives up use of some resources in order to enable control and data transmissions to the victim user terminal. More generally, interfering base stations can coordinate on transmission powers and/or spatial beams with each other in order to enable control and data transmissions to their corresponding user terminals.

The resource partitioning can be performed in time domain, frequency domain, or spatial domain. Time domain partitioning can better adapt to user distribution and traffic load changes and is the most attractive method for spectrum-constrained markets. For example, a macro base station can choose to reserve some of the subframes in each radio frame for use by pico stations based on the number of user terminals served by pico and macro base stations and/or based on the data rate requirements of the user terminals.

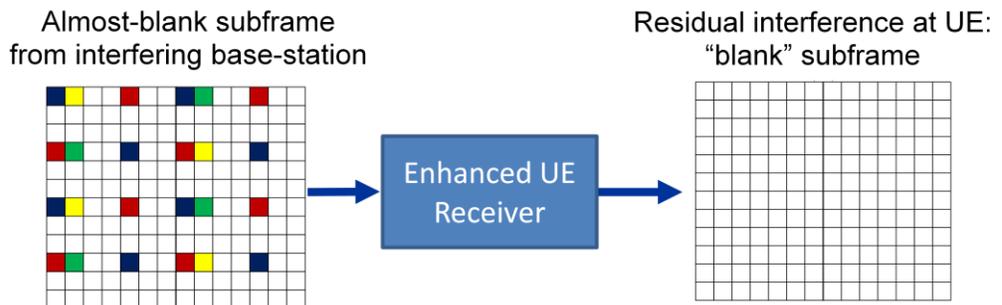
Figure 5 shows an example of time domain partitioning between macro and picos. Frequency domain partitioning offers less granular resource allocation and flexibility, but is a viable method — especially in an asynchronous network. Spatial domain partitioning can be supported by Coordinated Multipoint Transmission (CoMP), which will be further studied in 3GPP Rel-11.

Advanced Interference Management techniques such as resource coordination are needed to realize full benefits of heterogeneous deployments.



[Figure 5] Time domain resource partitioning between macro and pico DL: 50% resource reserved for macro; 50% resource reserved for picos.

For time-domain resource partitioning, a macro base-station can use almost blank subframes (ABSF) to reserve some subframes for picos. The macro base-station keeps transmitting legacy common control channels during ABSFs to enable full backward compatibility with legacy user terminals. The user terminals can cancel interference on common control channels of ABSF caused either by higher power macro stations or by close-by femto stations that the user terminals are prohibited to access. The function of the advanced receiver is illustrated in Figure 6. The interference cancellation receiver fully handles colliding and non-colliding Reference Signal (RS) scenarios and removes the need for cell planning of heterogeneous deployment.



[Figure 6] Advanced user equipment (UE) receiver cancels the reference signal in “almost-blank” subframes from interfering base-stations

3.2.2 Slowly-Adaptive Interference Management

In this approach, resources are negotiated and allocated over time scales that are much larger than the scheduling intervals. The goal of the slowly-adaptive resource coordination algorithm is to find a combination of transmit powers for all the transmitting base stations and user terminals — and over all the time and/or frequency resources that maximizes the total utility of the network. The utility can be defined as a function of user data rates, delays of QoS flows, and fairness metrics.

Such an algorithm can be computed by a central entity that has access to all the required information for solving the optimization problem, and has control over all the transmitting entities. Such a central entity may not be available or desirable in most cases for several reasons, including the computational complexity as well as delay or bandwidth limitations of the communication links that carry channel information or resource usage decisions. As a result, a distributed algorithm that makes resource usage decisions based on the channel information only from a certain subset of nodes may be more desirable.

The coordination can be performed via the backhaul (X2 interface in LTE). For example, pico stations can send load information and resource partitioning request to macro stations using X2 messages, while macro stations send resource partitioning response and update back to pico stations.

[4] Technology Performance

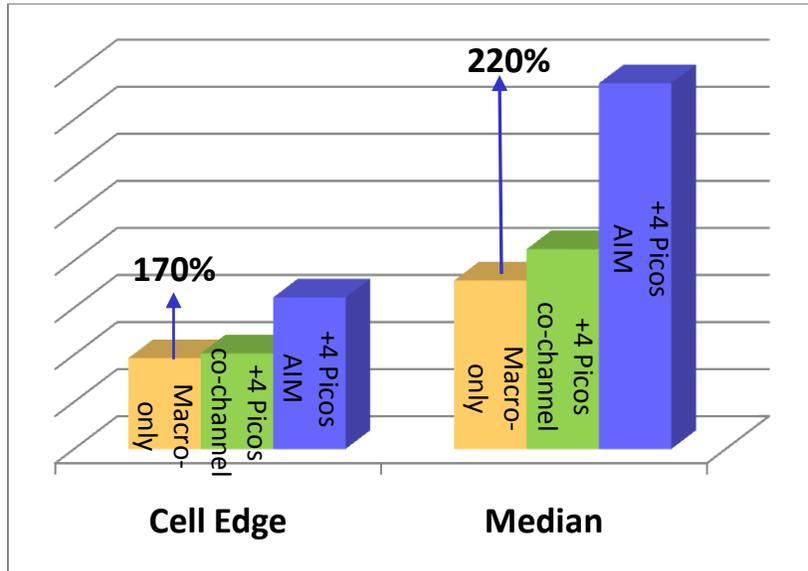
The potential performance improvement from LTE Advanced heterogeneous networks can be demonstrated in an example with mixed macro/pico deployment. The 3GPP evaluation methodology specified in [2] is used with configuration 1 (uniform layout). The network consists of macro base-stations (with 46dBm transmit power and 16dB antenna gain) and pico base-stations (with 30dB transmit power and 5dB antenna gain), with and without heterogeneous network enhancements.

Figure 7 shows the user data rate improvement using heterogeneous network features for downlink while Figure 8 shows the same improvement for uplink, both with macro inter-site distance (ISD) of 500 meters and 4 pico cells per macro base station. As seen in the figures, both cell-edge and median user rates are improved significantly as the result of the intelligent server selection and advanced interference management techniques described in the following sections.

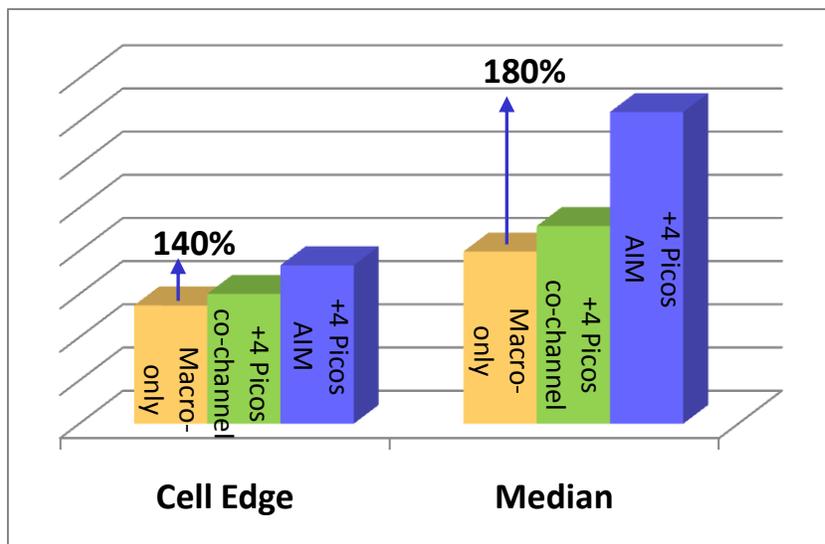
Figures 9 and 10 show the DL and UL user experience improvement using range extension and advanced interference management techniques, assuming an ISD of 1732 meters and 8 pico cells per macro base station. With larger macro cell size, more picos can be deployed per macro and heterogeneous network performance

Next generation networks should allow a uniform user experience across the cell by improving the cell edge and median data rates

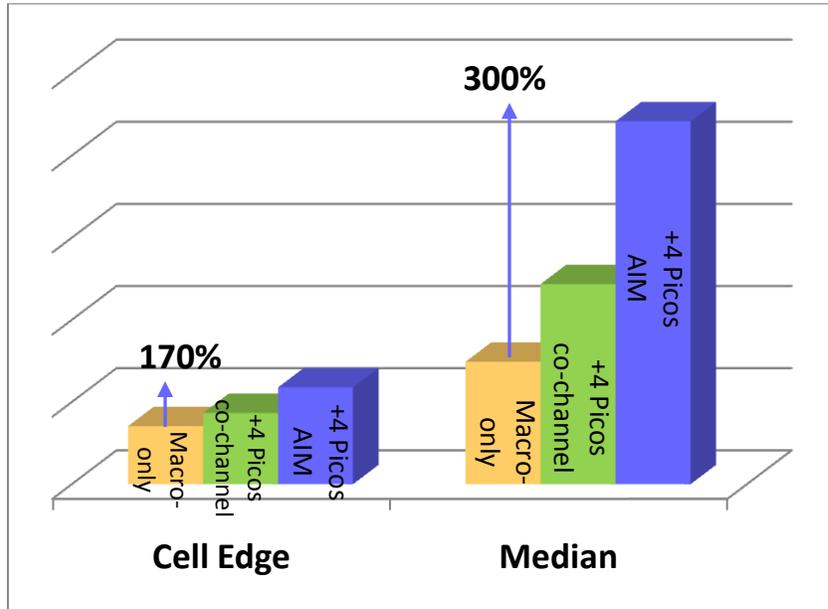
gains scale well with the number of picos. The LTE Advanced heterogeneous network provides a sustainable path to grow network capacity.



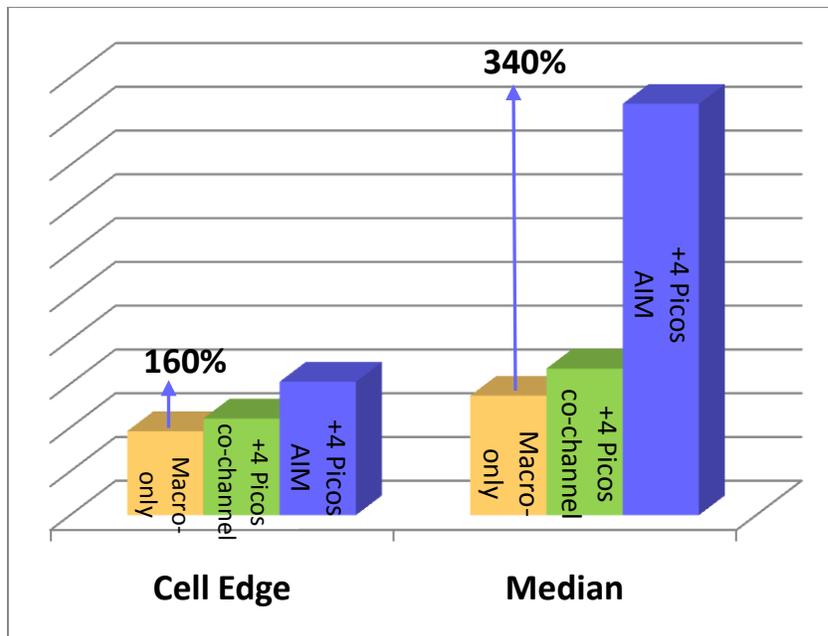
[Figure 7] Downlink Throughput in mixed Macro/Pico deployment with Advanced Interference Management (AIM), 500m macro inter-site distance, 4 picos per macro cell



[Figure 8] Uplink Throughput in mixed Macro/Pico deployment with Advanced Interference Management (AIM), 500m macro inter-site distance, 4 picos per macro cell



[Figure 9] Downlink Throughput in mixed Macro/Pico deployment with Advanced Interference Management (AIM), 1732m macro inter-site distance, 8 picos per macro cell



[Figure 10] Uplink Throughput in mixed Macro/Pico deployment with Advanced Interference Management (AIM), 1732m macro inter-site distance, 8 picos per macro cell

[5] Conclusion

Heterogeneous networks and the ability to manage and control interference in networks will allow for substantial gains in the capacity and performance of wireless systems in the future. Maximizing bits per seconds per hertz per unit area by controlling inter-base station fairness in the context of macro/pico networks enables a more uniform user experience throughout the cell, as demonstrated by the gains in the cell edge and median user experience.

Heterogeneous networks allow for a flexible deployment strategy with the use of different power base stations including femtos, picos, relays and macros to provide coverage and capacity where it is needed the most.

These techniques provide the most pragmatic, scalable and cost-effective means to significantly enhance the capacity of today's mobile wireless networks by inserting smaller, cheaper, self-configurable base-stations and relays in an unplanned, incremental manner into the existing macro cellular networks.

[6] Glossary

3GPP	Third-Generation Partnership Project
ABSF	Almost-blank subframe
DL	Downlink
eNode B	Evolved Node B
ICIC	Inter-cell Interference Coordination
LTE	Long-Term Evolution
LTE-A	Long-Term Evolution Advanced
MIMO	Multiple-input multiple-output
OFDM	Orthogonal frequency-division multiplexing
OFDMA	Orthogonal frequency-division multiple access
OTA	Over the air
QoS	Quality of service
RAN	Radio Access Network
RS	Reference Signal
SINR	Signal-to-Interference-and-Noise Ratio
TDM	Time-Division-Multiplexing
UE	User equipment
UL	Uplink

[7] References

[1] 3GPP TR 36.912 V2.0.0, "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Feasibility study for Further Advancements for E-UTRA (LTE-Advanced) (Release 9)", Aug 2009.

[2] 3GPP TR 36.814, Further advancements for E-UTRA physical layer aspects, Mar 2010.