Heterogeneous Networks (HetNets) using Small Cells

White Paper

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As a consequence of the proliferation of smart phones and tablets, data traffic is growing significantly, both on the radio access links and the backhaul infrastructure of mobile operators' networks. And although LTE and LTE Advanced offer higher data traffic throughput than that of 3G, given to their wider allocated bandwidths, the combined capacities of even these networks is not sufficient to meet projected future capacity demands. The conventional solution to increasing the capacity of LTE mobile networks includes splitting macro-cells and/or adding more sites. Both of these solutions require high CAPEX and OPEX, so mobile operators are seeking new and cost effective ways of increasing their network capacity. One solution is to deploy small-cell base stations (BSs) within their existing macro-cellular networks, an approach referred to as Heterogeneous Networks.

A Heterogeneous Network (HetNet) consists of two levels of BS: Macro-Cellular BSs (MCBSs) and underlying Small-Cell BSs (SCBSs); these can use the same technology (e.g. LTE) or different technologies (LTE and WiFi). It is well known that a HetNet not only increases the network capacity, but also provides better coverage and enhances the user's experience. These benefits are achieved by offloading data traffic dynamically from MCBSs to SCBSs using an algorithm based on several parameters such as the characteristics of the traffic, the required QoS and network congestion.

There is little doubt that to compete with their counterparts, the existing and future LTE operators will need to deploy HetNets. The critical question for them is whether to deploy LTE BSs or WiFi access points (APs) as their SCBSs. In this paper, the former is referred to as HetNets with LTE pico (small) cells and the latter as HetNets with WiFi cells. The choice between these two options depends on various factors such as cost (both CAPEX and OPEX), performance, handover capability, QoS, security and self-organising capability [1].

Cost

Since WiFi is becoming ubiquitous, the equipment and operational costs of WiFi networks are much lower than those of LTE pico-networks. In addition, WiFi operates in unlicensed frequency bands whereas LTE pico-cellular operates in licensed spectrum sharing the frequency of its overlying macro-cellular networks; this further increases the cost of HetNets with pico-cells.

Performance

The performance (in terms of throughput gain) for the both options (assuming 802.11n standard used for WiFi) is more or less the same if no new techniques are employed for avoiding interference. Throughput gain is defined as the increase in traffic throughput of the HetNet with small-cells compared with the overlaying macro-cellular network without small cells. For HetNets with LTE pico-cells, there is interference from the macro-cells if the radio resources are shared. For HetNets with WiFi, any interference comes from other WiFi networks. Any techniques, such as interference cancellation, co-ordination mechanisms or self-organising features used to minimise the interference will affect the performance of these HetNets. In the case of HetNets with LTE pico-cells, if the macro-cells and pico-cells use different frequency channels, the interference problem is solved and the throughput gain for this option will be much higher than that of HetNets with WiFi; however, this will be at the expense of lower bandwidth efficiency and higher cost because of the extra frequency spectrum needed.

The emerging 802.11ac standard is an enhanced version of 802.11n with wider bandwidth (up to 160 MHz), MIMO with up to 8 streams, multi-user MIMO, higher level modulation (up to 256-QAM) and beam forming capability. It is expected to offer a higher throughput compared with 802.11n. When this new standard is deployed, it is anticipated that the performance of HetNets with 802.11ac WiFi will outperform HetNets with LTE pico-cells.

The recent comparison of LTE Advanced HetNets with WiFi published by Qualcomm [1] shows that LTE Advanced HetNets with LTE pico-cells outperform LTE HetNets with WiFi significantly. This is largely explained by the advanced techniques introduced in the LTE Advanced HetNet standard, namely Enhanced Inter-cell Resource and Interference Coordination (eICIC) and, further, using advanced interference cancellation in the end user devices [1]. The difference in performances (in terms of throughput) for these two options increases from 20% for dense urban areas to 200% for suburban areas. The WiFi standard considered in this study is 802.11n; however, if 802.11ac were used instead of IEEE 802.11n, it is expected that the performances differences will narrow.

Seamless handover capability

The 3GPP standard defined a very tight coupling (full integration) between macro and pico networks for LTE and LTE advanced HetNets. Thus, seamless handover between these two networks is readily achievable. Whereas, the standard considers WiFi as a non-trusted system and very tight coupling between LTE and WiFi is not feasible. Although a mechanism is defined in the standard to interconnect the two systems, seamless handover (inter system handover) is not possible.

Quality of Service (QoS)

It is essential to guarantee the QoS of data traffic in any offloading scenario. For HetNets with LTE pico-cells, very well defined QoS mechanisms and classes are introduced. Both the macro- and pico-networks in a HetNet can guarantee the QoS demand of the offloaded data flows. Although 802.11e defines a set of QoS enhancements for WiFi and four QoS classes (conversational, streaming, web browsing and background), the requested QoS cannot be guaranteed because of the unpredictable interference and traffic load. WiFi is better suited for offloading non-sensitive data traffic [1].

Security

HetNets with LTE pico cells benefit from the very robust security mechanisms of the LTE standard. The 802.11i standard aims to enhance security in WiFi networks by introducing enhanced encryption, authentication and key management. Although this standard improves security in today's WiFi networks, it needs further enhancement to ensure robust and secure WiFi networks.

Self-organising features

Self-organising mechanisms make the dense deployment, planning and optimisation of small cells within HetNets simpler, faster and cheaper. The 3GPP Release 8 defines self-organising mechanisms such as Automatic Neighbour Relation (ANR) detection. ANR is the first feature in the overall solution for LTE self-organising networks (SONs). The SON solution was tested in a live LTE network in 2012 by TeliaSonera and Ericsson. Many LTE cellular operators including AT&T and KDDI have already announced the adoption of the SON solution.

The dense deployment of WiFi networks leads to their non-optimum performance from interference in unplanned WiFi networks. The self-organising features can facilitate the optimum use and sharing of spectrum to mitigate interference and, as a result, improve the WiFi performance. As far as we are aware no self-organising features are currently defined or implemented for WiFi networks.

Conclusions

The HetNet with small cells scenario is the best option for LTE and LTE-Advanced mobile network operators to satisfy increasing demands for higher capacity, better user experience and improved coverage, especially at the edge of cells. HetNets with LTE small cells outperform HetNet with WiFi cells in performance, handover mechanism, QoS guarantee, security and self-organising features, but their CAPEX and OPEX are much higher. HetNets with WiFi cells are best suited for offloading delay tolerant data traffic from macro-cells and they also operate in unlicensed frequency bands.

During the first phase the deployment of HetNets, WiFi (802.11n and 802.11ac) is preferable for offloading because of the ease of deployment, low cost of equipment (APs, routers, etc.) and operational costs. However, in future phases when much higher capacity, better user experience and better coverage are demanded, LTE small cells and WiFi cells could co-exist and complement each other within a HetNet to take advantages of both the allocated licensed and unlicensed spectrum bands, ideally by deploying small dual mode BSs - a small dual- mode BS which integrates an LTE BS and a WiFi AP on one box. In this scenario, delay tolerant data traffic can offloaded from macro -cellular networks to WiFi networks, and delay sensitive data traffic to LTE small cells.

Overall, there can be little doubt that WiFi (802.11n and 802.11ac) will be a complementary technology to LTE and LTE-Advanced in the future HetNet environment.

References

[1] A comparison of LTE Advanced HetNets and WiFi, Qualcomm Incorporated, October 2011.