BASE STATION APPLICATION OPTIMIZER

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Keywords: LTE, Access network architecture, Backhaul bottleneck.

Abstract: Expectation and requirements for future wireless communication systems continue to grow and evolve. Long-Term Evolution (LTE) is a recent effort taken by cellular providers and equipment vendors to step into wireless broadband market. The key enhancements target an introduction of new all-IP architecture, enhanced link layer and radio access. In LTE, one of the recurring problems is the bottlenecked backhaul links, connecting the cell sites with the core network. The basic idea behind the Base Station Application Optimizer is to replace the traditional base station with a smart entity, capable of analyzing and optimizing the user data in the application level. In particular, such unit can prevent unnecessary data from travelling though the bottlenecked backhaul network. The benefits of such entity are reduced latency, jitter and network deployment costs.

1 INTRODUCTION

Cellular operators are competing traditional broadband operators by offering mobile broadband access and IP services such as rich multimedia (e.g., video-on-demand, music download, video sharing) to laptops, PDAs, smart-phones and other advanced handsets. They offer these services through access networks such as High-Speed Packet Access (HSPA), Evolution-Data Optimized (EV-DO) and, in the near future, Long-Term Evolution (LTE). These access networks promise to deliver performance comparable to today's ADSL services, but with the added benefit of mobility and ubiquitous coverage. The new technologies offer mobile operators significantly improved data speeds, short latency and increased capacity.

Traditionally, most of the backhaul lines, connecting the cell sites with the core network, use TDM (E1, T1) lines, each providing up to 2 Mbps capacity. Though acceptable for voice and low data rate applications, E1 capacity is inadequate for higher data rates. Obviously, the direct result of the backhaul bottleneck is low utilization of the radio channels and an unsatisfying user experience. Enormous backhaul upgrade is required to new technologies such as Microwave, Metro Ethernet, cable, or xDSL to satisfy the high bandwidth demand. This upgrade is expected to be extremely expensive and its cost casts a real doubt on the profitability of enhanced network deployment. As a result, the operators are seeking data reduction solutions integrated with their network upgrades. The biggest cost challenge facing wireless service providers today is the backhaul network (Donegan, 2006).

The basic idea behind the suggested Base Station Application Optimizer (BS-OPT, for short) is to replace the traditional Base Station entity with a fast and smart entity, capable of analyzing and optimizing the user data in the application level. In particular, such unit can use its location in the operator network to prevent unnecessary data from travelling though the backhaul and core networks. Note that the suggested optimization is discussed here in the context of the base stations of LTE networks ("eNode-B") but it can be performed on any base station or access point (e.g., IEEE 802.16, IEEE 802.11).

2 LTE ARCHITECTURE

LTE is the next major step in mobile radio communications, and is introduced in 3rd Generation Partnership Project (3GPP) Release 8. LTE uses Orthogonal Frequency Division Multiplexing (OFDM) as its radio access technology, together with advanced antenna technologies.

Nossenson R. (2010).
BASE STATION APPLICATION OPTIMIZER.
In *Proceedings of the International Conference on Data Communication Networking and Optical Communication Systems*, pages 119-124
DOI: 10.5220/0003022601190124

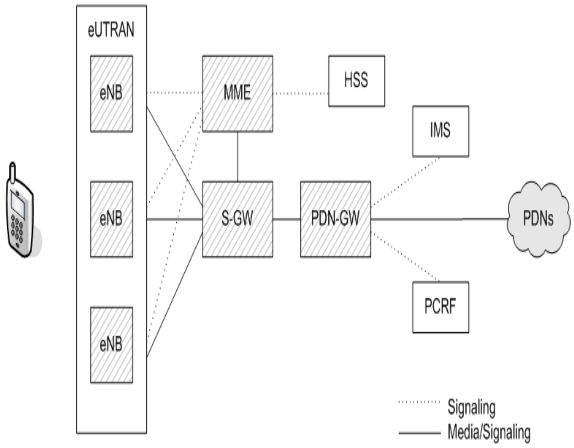


Figure 1: LTE/SAE High-Level Network Architecture.

When the evolution of the radio interface started, it soon became clear that the system architecture would also need to be evolved. Therefore, in addition to LTE, 3GPP is also defining IP-based, flat network architecture: System Architecture Evolution (SAE) as presented in Figure 1. The LTE–SAE architecture and concepts have been designed for efficient support of mass-market usage of any IP-based service. The architecture is based on an evolution of the existing GSM/WCDMA core network, with simplified operations. In the User Plane (UP), for instance, there are only two types of nodes (Base Stations and Gateways); while in current hierarchical networks there are four types (Node B, RNC, SGSN, GGSN). The gateway consists of two logical UP entities, Serving Gateway (S-GW) and Packet Data Network Gateway (PDN-GW). Flat architecture with less involved nodes reduces latencies and improves performance.

Another simplification is the separation of the Control Plane (CP), with a separate Mobility-Management Element (MME). A key difference from current networks is that it is defined to support packet-switched traffic only.

The only node in the Evolved Universal Terrestrial Radio Access (eUTRAN) is the eUTRAN Node-B (eNode-B, eNB in Figure 1). It is a radio base station that is in control of all radio related functions in the fixed part of the system. Typically, the eNode-Bs are distributed throughout the networks' coverage area, each residing near the actual radio antennas. The interface between the eNode-B and the gateways is the S1-U; the interface between the eNode-B and the MME is the S1-C. The interface between peers eNode-Bs is the X2. The backhaul links are implementation of these three interfaces and any required aggregation.

A noteworthy fact is that most of the typical protocols implemented in today's Radio Network Controller (RNC) are moved to the eNode-B. The eNode-B is also responsible for header compression, ciphering and reliable delivery of packets. On the control plane, functions such as admission control and radio resource management are also incorporated into the eNodeB. Benefits of the RNC and Node-B merger include reduced latency with fewer hops in the media path, and distribution of the RNC processing load.

The Policy and Charging Resource Function (PCRF) is the network element that is responsible for Policy and Charging Control (PCC). It makes decisions on how to handle the services in terms of QoS, and provides information to the PDN-GW, and if applicable also to the S-GW, so that appropriate bearers and policing can be set up.

The Home Subscription Server (HSS) is the subscription data repository for all permanent user data. It also records the location of the user in the level of visited network control node, such as MME.

The IP Multimedia Sub-system (IMS) is service machinery that the operator may use to provide services using the Session Initiation Protocol (SIP).

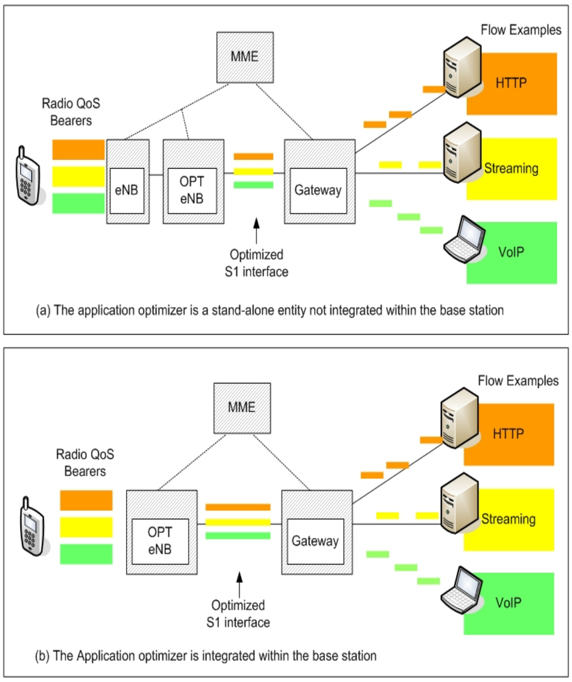
For additional information on LTE network see (Holma and Toskala, 2009, Dahlman *et al.* 2007).

3 BASE STATION APPLICATION OPTIMIZER

We suggest a simple solution to the backhaul bottleneck problem. The traffic load on the backhaul links can be reduced by replacing the traditional Base Station entity with the BS-OPT, a smart entity capable of analyzing and optimizing the user data in the application level. This section describes the suggested solution architecture, support for user mobility and finally discusses possible benefits and limitations.

3.1 Architecture for the Base Station Application Optimizer

Two options are considered for the new BS-OPT architecture as described in Figure 2. In the first architecture the BS-OPT is a stand-alone entity, not integrated inside the base station, probing and then analyzing and manipulating the traffic. The second architecture is an integrated unit inside the base station. Pros and cons of each solution are discussed below.



(a) The application optimizer is a stand-alone entity not integrated within the base station

(b) The Application optimizer is integrated within the base station

Figure 2: Data flow with the Base Station Application Optimizer.

The stand alone architecture is described in Figure 2A. The solution in this case is a separate hardware and software package. It is located after the base station ("bump in the wired") and is capable to probe its entire traffic with very low delays. Note that for each base station we should associate its corresponding optimizer.

The benefit of this structure is mainly the reduced dependence on the base station evolution. This allows a complete freedom in the solution life-cycle. Additionally, it provides a flexible network structure: the solution can be installed at part of the operator network and not on the entire network. However, stand alone architecture means that we should face the challenge of very-fast probing, analysis and manipulation of the traffic. In addition, it means multiple installations which are very expensive. Furthermore, the most critical drawback of this architecture is difficulties in supporting user mobility. To support user mobility a new interface should be defined between peer optimizers which result in higher system complexity and cost.

The solution in the case of integrated architecture is a software package installed on the base station as presented in Figure 2(b). This architecture saves the probing time and allows an elegant and simple application solution. User mobility is supported easily using, for example, the regular buffer forwarding procedure defined by the 3GPP specifications (3GPP TS 36.300, 2009) for LTE as described in Section 3.2 below. However, the main disadvantage of this architecture is the required collaboration with base station evolution.

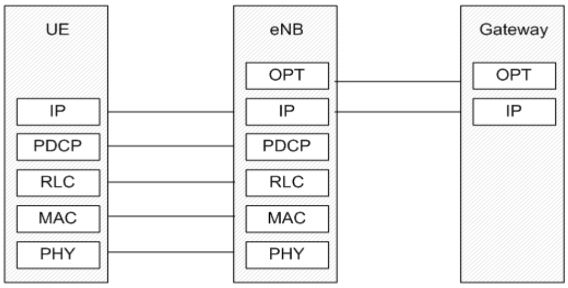


Figure 3: Protocol Stack for the User Plane with BS-OPT and gateway optimizer.

To avoid the difficult multiple installations and to obey the high-speed requirement we recommend implementing this solution as integrated software within a base station (Figure 2 (b)).

Regarding LTE networks, the suggested protocol stack of eNode-B with application optimizer is described in Figure 3. Additionally, we study the potential benefits of applying supporting optimization algorithms at the operator gateway. The corresponding suggested protocol stack of the gateway is presented in Figure 3 too.

3.2 User Mobility Support

The LTE handover procedure is described in Figure 4. Using the integrated architecture of the BS-OPT, user mobility can be supported as follows. At step 8, the source eNode-B performs buffer forwarding of the user buffered packets to the target eNode-B. The application optimization layer provides the user data to the lower layers. Thus, all optimized user data will be forwarded as usual.

Regarding the user data which is currently in the optimization process, we have two options: either to cancel the optimization process as a part of step 18 (release resources), or continue with the optimization and buffer forwarding. The source eNode-B continuing processing resources might save more processing resources at the target eNode-B. For example, if objects from a particular web page are already stored in the source eNode-B cache, it will be better to transfer them from the source eNode-B to the target eNode-B and to avoid the double page request from the server.

We believe that both options should be implemented and the choice between them should be made on-line dependent on the specific traffic characterization.

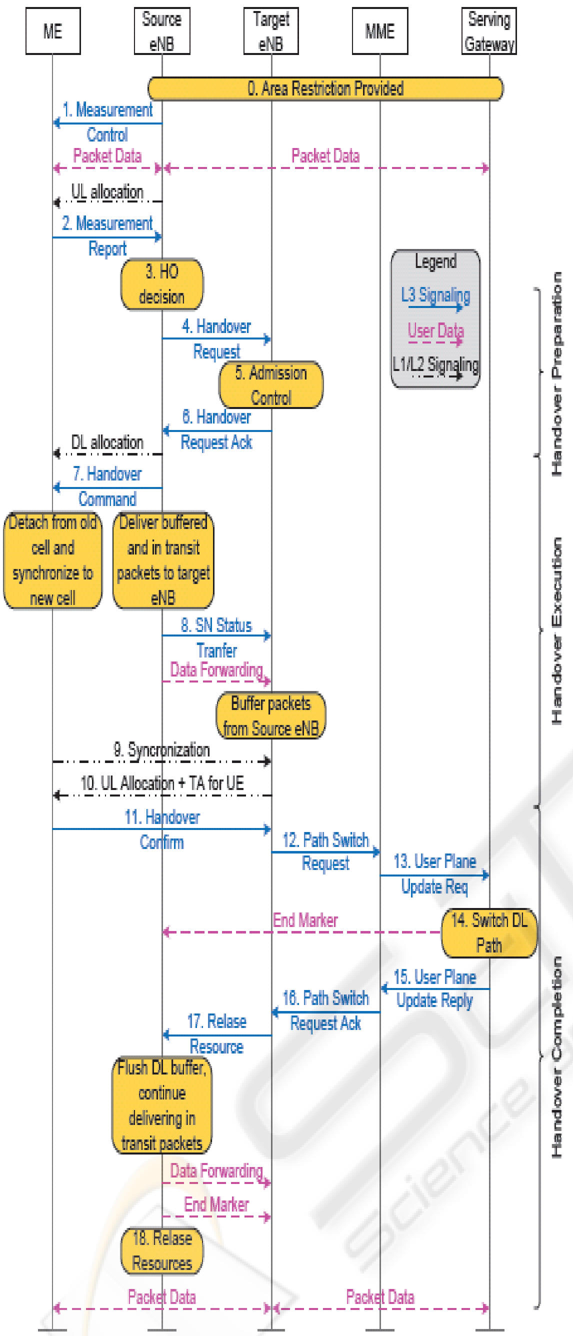


Figure 4: Message chart of the LTE handover procedure. The control plane messages (solid and dot-dashed arrows) and the flow of the user packets (dashed arrows) are reported (3GPP TS 36.300, 2009).

3.3 Benefits and Limitations

The essential benefit of application layer optimization in the base station (BS-OPT) is data reduction at the backhaul bottleneck. This can help in reducing the total backhaul upgrade costs and improving the user experience by providing higher actual data rates and shorter delays.

A major latency and data reduction can be achieved by implementing an application cache at the BT-OPT. Cache such as web cache, P2P or streaming cache can reduce the traffic significantly as a function of the cache size and the user behaviour. Furthermore, researches have shown that users do not tend to move a lot while consuming data applications. In fact, according to (Halepovic and Williamson 2005), users have high probability (over 85%) to be connected to the same cell- the so-called "home-cell". Obviously, such pattern of user behaviour increases the cache hit rate dramatically.

Additional data reduction can be done by replacing many live video streaming between each user and an internet live video streaming server (see Figure 5(a)) with a single live video stream between the BS-OPT and the streaming server, and only then delivering uni-streams to the specific users between the BS-OPT and the users' in the cell (see Figure 5(b)). The BS-OPT should replace the Internet Group Management Protocol (IGMP) role and establish the users multicast group memberships. The BS-OPT can control the transformation of the single video stream into multiple uni-streams according to the multicast group members list. Meaning, it can hold a group table with all multicast group members' details similar to IGMP.

Using location information, BT-OPT can help in optimizing P2P traffic using algorithms similar to P4P (Xie *et al.* 2008). The location information can help optimizing the traffic path between peers and reduce the file download latency while reducing network resource consumption as demonstrated in Figure 6B. However, implementing this feature required capabilities of IP routing with mobile users within the BT-OPT, such as suggested in Cellular IP (Valko, 1999).

Additional data reduction and improvement in the user experience can be achieved by fitting the proper picture resolution/format, video format and transfer rate to the handset capabilities and to the available resources in the cell. Another example of simple possible data reduction at the BT-OPT is file compression. Many handsets do not support compression formats. Once the User Agent (that is, the browser application) of the handset reports that it does not support compression formats, the web servers avoid the file compression and response with acceptable file format. The BT-OPT can overwrite the relevant HTTP header to reflect compression format support resulting in a compressed file

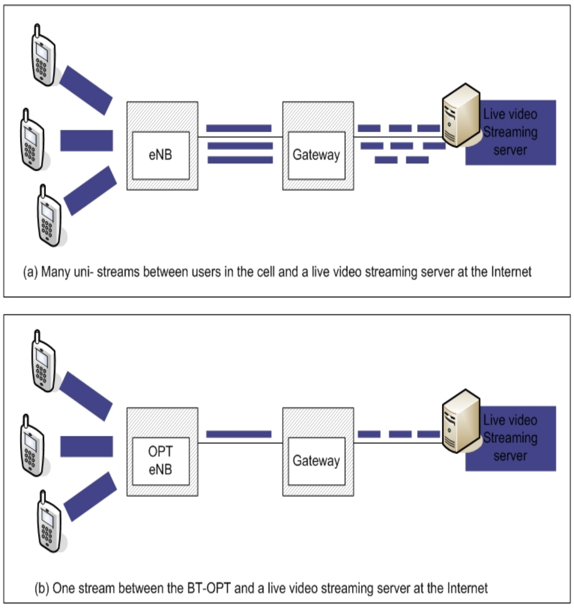


Figure 5: Using BT-OPT to optimize live video traffic.

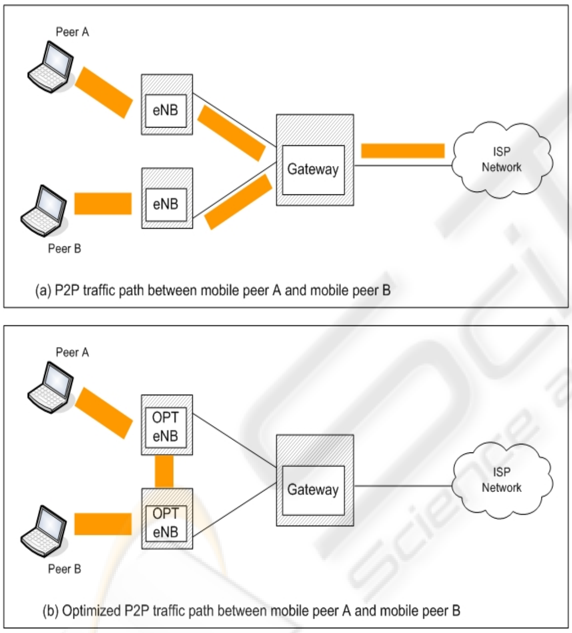


Figure 6: Using BT-OPT to optimize P2P traffic.

transmission by the web server. The BT-OPT can then decompress the files and transmit them to the handset according to the original file format. A supporting Central Optimization Entity at the operator gateway can provide additional data reduction such as compression of files that were not compressed by the web servers or Delta compression of any data traffic between the gateway and the BT-OPT.

However, implementing Deep Packet Inspection (DPI) technology in the base station is simple in concept but complex in practice. Conceptually, inspecting a packet to determine subscriber and application type and then acting on that information looks easy. However, traffic rates and rapidly evolving applications add complexity. Based on present data rates, packet rates are already staggering. Each LTE user UL/DL channel can carry millions of packets per second. At that speed, there's only ~100 nsec to receive and inspect each packet, determine its application, perform the optimization algorithms, modify it if necessary, and forward it to the proper destination according to the optimization plan. As a result, the base station must include strong multi-core, multi-threaded processors for packet inspection.

4 PERFORMANCE EVALUATION

Performance of the BT-OPT is evaluated by modifying the Qin-long et al. LTE/SAE model (Qiu *et al.*, 2009) for ns2 network simulator. Since we are still working on the simulations, we can only discuss preliminary results at this stage. The major modifications (see Figure 7) of the network model include extending the e-NodeB to support HTTP caching, IP routing, and streaming multicasting management. The data reduction on the backhaul link is measured by comparing the sum of the packets (uplink and downlink) on the queues between the gateway and the OPT- eNodeB (S1 interface) with the sum of the packets on the queues between the gateway and the traditional eNodeB, under the same traffic generation. Other performance parameters, such as average delay and jitter are measured using the ns2 statistics.

Traffic scenarios include 5, 10 and 20 UEs with different traffic QoS classes. Peer-to-peer traffic is simulated by file download between peers UE in the cell. Regarding the streaming traffic, we see that as the number of users in the multicast group becomes larger, the performance improves dramatically, as expected. Regarding the web traffic, the performance improvement highly depends on the assumed cache hit rate. To improve our understanding on the solution's limitation, currently we are trying to evaluate the effect of the additional processing time at the OPT-eNodeB on the performance parameters.

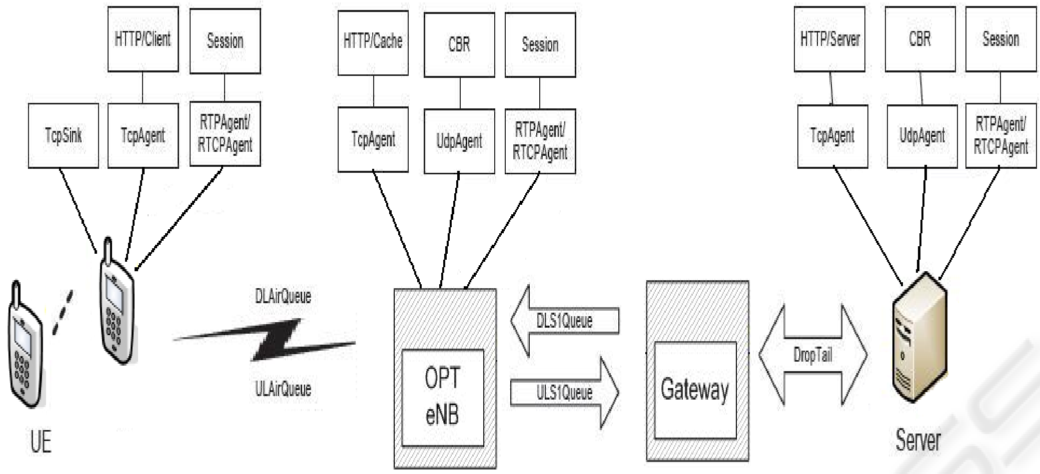


Figure 7: Simulation model.

5 CONCLUSIONS

In this paper we presented a novel solution to the backhaul bottleneck problem of wireless broadband networks: the Base Station Application Optimizer. Benefits of the BS-OPT are reduced backhaul upgrade costs and improved user experience by providing higher actual data rates and shorter delays. However, implementing fast Deep Packet Inspection (DPI) technology in the base station is complicated and requires careful design.

Future work includes additional simulations to improve the evaluation of the system potential and its limitations.

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