SMART CACHING IN MOBILE IP ENABLED NETWORKS

Stephan Goebbels

RWTH Aachen University, Faculty 6, Chair of Communication Networks, Aachen, Germany
sgs@comnets.rwth-aachen.de

***Abstract* – This paper will present a new caching strategy to support mobile users in heterogeneous network environments. By buffering user data at the edge of the core network cabled and wireless sections are decoupled, so that the end-to-end performance will be improved. The protocol and architecture similarity to the MobileIP approach will be used to motivate the cooperation and integration of both techniques. The new system concept for caching-enabled wireless all-IP networks is introduced and evaluated.**

The simulation results will show how smart caching will improve the overall network performance perceived by end users. The throughput will be drastically increased and for non-real-time services a virtually continuous broadband connection will be provided even in case of fragmentary network coverage.

The paper will expose the performance gain of the new protocol and its impact on end user convenience.

Keywords – Smart caching, all-IP networks, heterogeneous environments, Mobile IP.

1. Introduction

The massive growth of the Internet especially in wireless areas comes along with completely new requirements for communication protocols and technology. The evolution of WiFi radio systems is one of the core research areas of recent days but still broadband wireless access for mobile users is not yet reached. Also the improvement of the IP protocol suite towards Mobile IPv4 or even MIPv6 will suffer from the inherited problems of the early Internet protocols where address and location was one entity [1].

Also the tendency towards all-IP networks, which includes not only wireless LANs or WANs but as well cellular networks like UMTS, is already arisen. The wireless access will always have to deal with time consuming intersystem handovers and massive fluctuations in supplied bandwidth and latency, which vitally depends on the currently used air interface and its corresponding communication technology.

To bridge over situations of poor wireless access or interrupts due to intersystem handover smart caching can be used to improve network performance [2]. It will allow customers to perceive a virtually continuous broadband network connect at least for non real-time services [3].

Therefore smart caching tries to proactively store enough data at the end device in order to pretend the user a continuously connection in case the wireless link is broken. This could for example mean that during a multimedia streaming a certain amount of packets is stored at the end device so that longer periods of low bandwidth connection can be by-passed. Also an ahead of time download of all pages linked form the current webpage allows the user to further surf the web even if the connection is broken.

But all these approaches require an optimization of the download rates in areas of wireless broadband access in order to prefetch data which is consumed in periods of lost wireless connection. Nowadays transfer rates of WiFi connections are not exploited by users due to the lack of user requests or due to limitations of the backbone connection. Usually an end-to-end connection in the Internet allows only transfer rates smaller than the maximal ones of WLAN networks although each link in the backbone is much more capable. The obvious reason for this is that the links in the backbone have to be shared with thousands of other users while WiFi cells are only visited and used by a very small number of users simultaneously. To overcome the unbalance between achievable throughput in linked state and the actual transfer rates it is necessary to enable efficient buffering techniques. A continuous streaming of data through the backbone in order to fill up buffers at the edge of the network allows a massive transfer of data in phases of WiFi connection. The buffering is performed in the middle layer of Figure 1 which aggregates all connected radio systems.

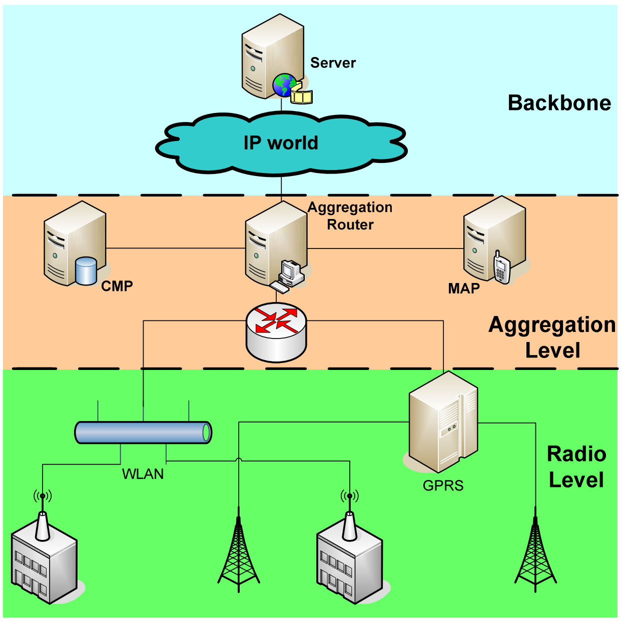

Figure 1 : All-IP system Architecture

This cached data can be purged to fully utilize the wireless link when the connection is established. The node which carries out the buffering of data between server and client is called Caching Media Point (CMP).

The remainder of this article is structured as follows. In chapter 2 the smart caching approach and its integration into the current or a near future network architecture is given. This integration is further elaborated in chapter 3. The used simulator and the scenario setup is introduced hereafter, which is followed by chapter 5 comprising the simulation results. Some further improvements of the protocol and the system architecture are listed in chapter 6. Finally the paper is summarized and concluded.

2. Motivation

The future will reveal a mixture of several mobile radio technologies which will coexist beside each other. They offer different capabilities with respect to e.g. bandwidth, delay, mobility and handover support. This will result in a patchwork of radio illumination of different radio interfaces so that the mobile user will roam within a very heterogeneous environment.

Periods of broadband wireless access will be interrupted by phases of only basic access. Compared to the backbone connection the wireless link either exceeds the capabilities of the cabled end-to-end connection or is much less capable, like experienced from packet-switched cellular networks. A WLAN easily reaches several 10^{th} of Mbit/s which is more than a usual end-to-end connection may offer. But of course ordinary backbone connections easily outperform cellular systems like GPRS and even UMTS. Thus, linked via WLAN the wireless connection is unchallenged. While switched to the cellular system the backbone could deliver much more data than the last wireless hop may deal with.

Smart caching will overcome these problems by separating the end-to-end into two discrete sub-connections. Incoming packets are buffered in a caching node and from there on forwarded to the end terminal. This separation comes along with several advantages. For example the route between server and Caching Media Point is completely covered by legacy cabled IP links like in most of today’s Internet. Therefore protocols like TCP are most suitable to handle the traffic between these nodes since mobility issues may completely be ignored. On the other side the second part of the connection consist only out of a short wired section and the wireless link itself. This allows a fast reaction on intra- and even intersystem handovers. Latency in the case of connection reestablishment will be much reduced and an optimal utilization of the bandwidth of the wireless network is assured.

The permanent intersystem handover and the variety in cannel abilities like bandwidth will burden the all-IP backbone with additional management and protocol problems. In Figure 1 these facts are depicted by the combination of a WLAN and a GPRS network.

In GPRS networks the Serving GPRS Support Node (SGSN) is the gateway from the cellular into the IP core network. Although WLANs already interconnect several IP nodes there usually is one gateway router which connects the local Ethernet to the outside world. Beyond these points both systems are equivalent from the IP perspective. Thus for users which interchange between the access technologies this is the first common point to reroute incoming packets.

For the support of mobility in IP networks the Mobile IPv4 (MIPv4) [4] and latter on Mobile IPv6 (MIPv6) [5] was developed by the IETF [6]. Both protocols based upon the principle to use one permanent node as a point of reference, so called Home Agent (HA), for ingress IP packets which are then forwarded to the current position of the mobile node. Due to the fact that a mobile user can travel around the world the hop distance between reference point and current position may be even bigger than the actual server-client distance. Therefore the reaction on handovers will occur very slowly and ineffectively. This problem should be covered be Hierarchical MIP. By splitting the mobility management into two layers the support of handover should be much improved. While there is still the HA as an interface for the incoming packets the data is not directly forwarded to the Mobile Node (MN) but it has to pass through another MIP routing node, the Mobility Anchor Point (MAP) [7] [8]. This node is responsible for the micro-diversity of the mobility support. Each self-containing area is controlled by the MAP. If handovers take place between access points within the same MAP area the HA is not informed. Packets are still forwarded to the same MAP and from there on distributed to the current position of the mobile terminal. Only if the border of a MAP area is crossed the HA has to be updated. This procedure is called macro-diversity. So there will be introduced a layer which is responsible for macro-diversity, controlled by the HA, and one for micro-diversity, ruled by the MAP.

The latter perfectly fits to the idea of smart caching. A node which is serving all kind of networks and, within them, all included access nodes in a certain self-contained area suits to the MAP as well as to the Caching Media Point. Therefore the next logical step will be to collocate the two entities within on node.

Moreover the smart caching protocol may benefit from the mobility triggers of the mobile IP protocol. The first node which is informed about a changed network location is logically the MAP which would mean that the buffered packets in the CMP would directly be rerouted to the new address with a minimum of delay. Also the macro-diversity functionality of HIP would fit to the smart caching idea as the choice of a new MAP would also mean that a new CMP would be found. Furthermore the server which deliver information to the CMP and from there on to the client would get the update of the new serving CMP in the shortest possible time.

The strong integration of both systems and protocols is depicted in Figure 1. At the bottom resides the actual access node of the different wireless networks. All nodes of the same network are gathered and combined by aggregation node. For the GPRS network this is the SGSN. For a WLAN the gateway router between the

Ethernet and the backbone network is a suitable candidate although usually wider areas of WLAN coverage are not summarized within one Ethernet. However the traffic of the different Ethernet gateway nodes may be gathered by another high level router. On top of these aggregation points there is gateway router to the backbone which is directly linked to the MAP as well as to the CMP. However it is possible to integrate both logical entities directly into the router which would make protocol integration and interaction even easier.

The positioning of the CMPs within the network is of major influence for the system performance. It has to be close to the wireless link but however deep enough in the backbone to simultaneously cover different access technologies and access nodes of the same network, in order to fully control all access networks of a specific area. The statically positioning of such nodes within the network is however out of scope of this paper.

3. System Concept

The principle of smart caching bases upon the separation of the end-to-end connection between server and client. The Caching Media Point in the middle breaks it down into two separated communication paths.

As smart caching is independent of the underlying transport protocol the particular connections between server, CMP, and client are covered by legacy IP and transport protocols.

Figure 2 illustrates the three main entities which are involved in the smart caching architecture and their interrelation. The outer nodes are the usual communication partners. In the middle resides the caching node which receives data from the server and forwards it to the client like a legacy IP router would do. However for the caching of information and the separation of the communication path it is necessary to use a termination for the ingress path of the server. The data has to leave the transport layer and to go up to the caching entity. Therefore a caching client receives all incoming packets and re-routes it to the caching entity which buffers the data. The structure and the organization of this buffer is not relevant for the applicability of smart caching. For simplicity reasons this entity can be seen as an elementary FIFO queue which temporarily stores the packets until they are forwarded to its final destination, the client node.

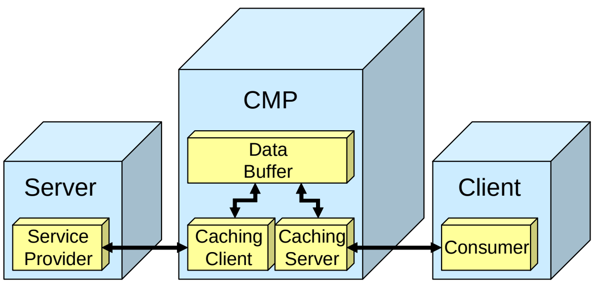

Figure 2 : Smart Caching Protocol

In the CMP the caching server takes over the task to retrieve the information out of the data storage and forward them to the actual communication client if data is requested by the communication client. The different massages which are exchanged between the smart caching entities are depicted in Figure 3 below.

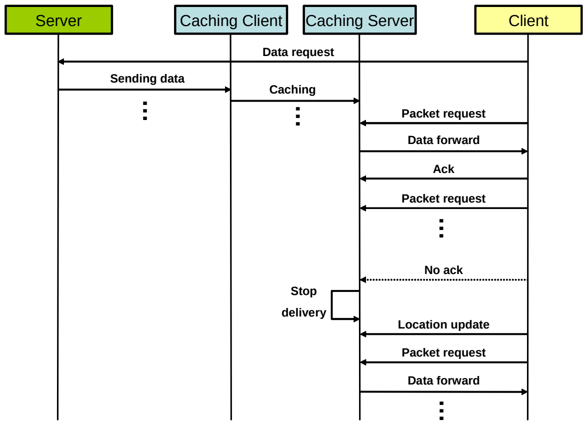

Figure 3 : MSC of Smart Caching Protocol

The first step of each communication session is the request for a specific service from the client. But contrary to legacy systems the data is not directly send to the final destination but routed to the CMP node. Here the information is received by the caching client entity of the CMP.

The incoming packets are handed over to the actual storage entity which keeps them until they are needed by the caching server. This procedure is combined in the message "caching" exchanged between client and server (compare Figure 3). The second sub-connection exists between client and caching server. The packets are actively requested by the client entity. Responding to such a request one data packet is forwarded to the client. The receipt of such a packet is acknowledged by the client in order to allow the server to remove the data out of the cache. As long as the connection is available the data is forwarded to the client. If the wireless link is broken due to a handover or the user has left the coverage area of the WiFi network no more packets are requested and the delivery is held. However the filling of the buffer in the CMP continues as this sub-connection is no more influenced by such an interruption.

As soon as the client regains a connection to the core network a location update is send to the caching node. Thereby it is irrelevant whether it is the same access network as before or an inter-system handover has taken place as long as the access node is controlled by the same CMP. After the reestablishment of the connection the transmission of packets may continue. But as in the meanwhile a certain amount of packets was already stored in the cache it is now possible to fully exploit the bandwidth of the wireless hop until the cache is exhausted and the CMP has to wait for new incoming packets of the server.

For all involved packets in the smart caching protocol the in Figure 4 shown packet structure is assumed. The IP payload is extended by a **S**mart **C**aching header although the actual data payload is not influenced. Signaling packets of the smart caching protocol are transmitted in the same format only the data payload is left out.

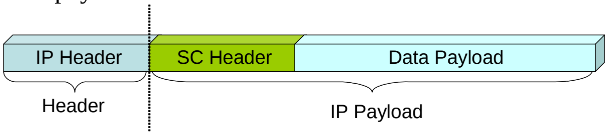

Figure 4 : Packet Structure of Smart Caching

In Figure 3 it can be seen that there is a major imbalance between the signalling flow on the first hop between server and CMP and the second hop between CMP and client. Most of the control traffic is on the latter hop and only the actual packet transmission takes place on the first one. This displays very well the advantages of the new protocol as control sequence from the client only have to traverse the distance to the CMP instead of the whole way to the server. Session reestablishment and protocols for flow control or ARQ mechanisms will work much faster and the system latency will be reduced. Also protocol overhead will be kept away from the backbone network.

4. Simulator and Simulation Scenario

Smart caching should operate on top of an all-IP network. Therefore the network simulator NS-2 [9] was chosen as the appropriate simulation environment. It can easily provide a common IP layer which can be extended by all kind of protocols. Moreover WLAN and Mobile IP modules are already available.

The in chapter 3 documented smart caching protocol and all its components are included in the simulation environment. The mobility support is taken over by the implemented MIPv4 protocol suite. Specific nodes of the simulator are enhanced with smart caching functionality while others are kept in there legacy shape. Therefore smart caching can be seen as an overlay structure on top of the common IP layer.

For all performed simulations a traffic source somewhere in the backbone was assumed. The source tries to stream a dataflow of net 400 kbit/s to the client. The packet payload size is set to 500 Byte. Depending on the setup of the simulator the packets are routed through the CMP or directly send to the client. The backbone connection is limited to 1Mbit/s which is enough to carry the offered traffic. This part of the scenario is left out in Figure 5 as it has only minor relevance for the simulation and its results.

As shown in Figure 5 the CMP is directly connected to the backbone network. The Home Agent (HA) required by the MIP protocol is connected to the CMP via a 1 Gbit/s link which comes very close to a collocation of both entities. Due to this fact, the HA is not display as a separate entity. The positioning of the HA at this location emulates the employment of hierarchical MobileIP with a MAP at the same position. On the other side the CMP controls an area with 10 WiFi access points which partly illuminate the simulation scenario. All APs are directly linked to the CMP by a 100 Mbit/s connection. For the connection between APs and mobile node the 802.11b WLAN protocol was used which is already provided by the NS-2 simulator. It allows a connection bandwidth of 1 Mbit/s for protocol signalling and of up to 11 Mbit/s for payload data. For all transmissions the RTS/CTS mechanism is activated and all received data packets are acknowledged by the recipient.

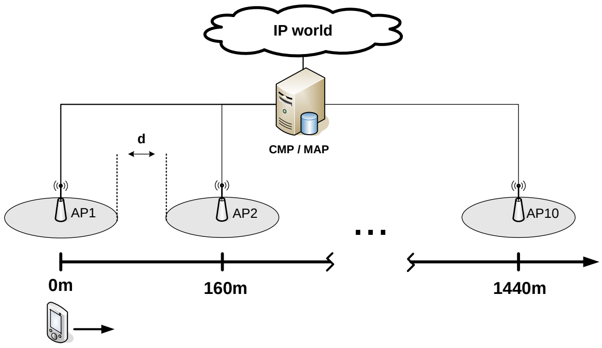

Figure 5 : Simulation Scenario

Compared to the backbone capacity the WLAN link is not such a high improvement with respect to the throughput. But the simulation results will show that with smart caching still a major performance gain can be reached.

Due to simplicity the APs are set behind each other and the mobile terminal is traversing the scenario starting at AP1 on the left until it reaches AP 10 at the right end of Figure 5. The distance between two successive APs is set to 160m and the velocity of the terminal is fixed to 1 m/s. Therefore the terminal has phases of WiFi access but also connection breakdowns if it leaves the coverage area. The coverage area is one simulation parameter and varies between a cell radius of 8 up to 60 meter. Thereby the coverage rate in the whole simulation can alter between 10 and 75% of the complete simulation scenario.

As already mentioned above, the packets in the CMP are actively requested by the client. By doubling the frequency of packet requests of the client compared to the sending frequency of data packets on the server side it is guaranteed that packets in the CMP does not have to wait very long until the are requested by the client.

Arrived at the final destination data is not consumed directly since it should be used to bridge over the idle gaps between two overage areas. Therefore in the end device the data is stored again until it is needed. For a video stream it would mean that packets are buffered until the video sequence reaches the corresponding position. Therefore the client application in the simulator consumes the incoming data with a rate of 300 kbit/s. This is smaller than the offered traffic from the source node so that even in legacy systems some packets might be buffered to bridge smaller interrupts in the wireless connection.

To compare all achieved results with conventional protocols it is possible to switch of the smart caching functionality so that the packets are delivered directly to the client only supported by the MIPv4 protocol to handle the terminal mobility.

5. Simulation Results

The advantage of smart caching should be that the throughput of the end-to-end connection is improved and packets are faster delivered to the end user. To verify this, several simulations are carried out and parameters like delay, current throughput, overall throughput and amount of buffered data is monitored and evaluated. The results are compared to corresponding reference scenarios where the smart caching functionality is disabled. Thus, it is possible to measure the performance gain of the new technique.

The parameter which is changed in the different simulations is the coverage ratio of the wireless access. Namely, how much percent of the examined simulation scenario are covered with WiFi access.

As smart caching has a significant impact on the reachable throughput of data transfer sessions a major part of the evaluation of the simulation results is dedicated to the end-to-end throughput.

But also the delay which a user perceives while waiting for specific information is of major influence on the consumer satisfaction. Therefore in a second evaluation step the delay of each packet is analyzed in detail.

5.1. Evaluation of Throughput

For the evaluation of the throughput a user terminal traverses the complete simulation scenario (compare Figure 5) starting at AP 1 and move with constant velocity until it reaches AP 10. Hereby it establishes a connection to the Internet and requests data from a server directly at the beginning of the simulation. Since the terminal is close to an AP a wireless link is available and the transfer of packets may begin. For smart caching this means that packets are actively requested from the CMP and therefore the data of the server is forwarded to the client.

After a certain time the border of the coverage is crossed and the wireless link is broken. While covering the distance to the next cell border no connection to the server is available but still packets are sent from the server to the CMP and stored in a cache. After reaching the coverage of AP 2 the connection is reestablished and the client request new packets form the storage of the CMP. As simultaneously the Mobile IP protocol takes care of the required routing updates in order to reach the new node location the packets can be again forwarded to the mobile node. This procedure repeats several times until the mobile node stops besides Access Point 10.

In Figure 6 current throughput perceived by the mobile node is illustrated for the first three APs. The doted rectangular curve depicts the coverage area of the different access points. However the reached level on the Y-axis has no further meaning it just shows where a WLAN connection theoretically is possible with respect to the radio conditions and where not.

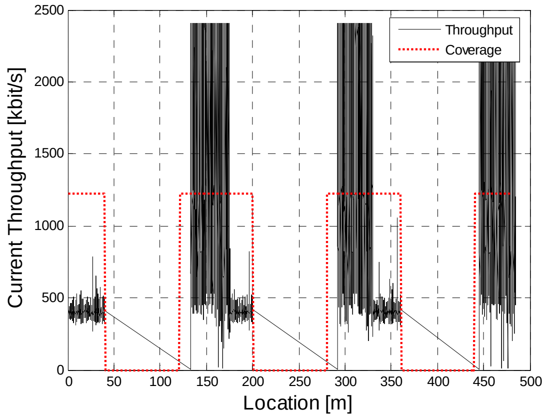

Figure 6 : Current Throughput vs. Location

At the start the simulation reacts similar to a legacy approach as all packets are directly forwarded to the client node. The offered traffic of 400 kbit/s is matched by the experienced throughput. After the wireless link is broken the current download rate decreases continuously. This effect occurs due to the graphical representation of the measurement data. As no packet comes in between both cell borders the value for the current throughput is not updated. By simply connect the last value in the old and the first value in the new cell the constant decrease rate arises although in reality no packets arrives in this idle phase.

Between the entrance in the coverage area and the reestablishment of the link is a certain period which is used up by the MIP protocol for the detection of a responsible Foreign Agent (compare the Mobile IPv4 standard), updating routing tables and changing the address where the mobile node can be reached. Afterwards the transmission of packets between CMP and client can be resumed. Since enough data is already buffered in the cache it is possible to use up the capacity of the wireless link and stream as much as possible packets. Here a throughput of more than 2 Mbit/s is reached. This value is smaller than the theoretically maximum bandwidth of the wireless link but this effect is due to the overhead of the 802.11b and the smart caching protocol. After exhausted the buffer the transmission rate drops down to the old value of 400 kbit/s. This procedure continues in each newly entered WLAN cell.

Figure 7 illustrates the cumulative throughput which is experienced by the end user. Four different scenarios are compared. The uppermost horizontal line represents the maximum cumulative throughput which could be reached if 100% network coverage would be provided. The lower vertical line represents the theoretically reachable throughput for coverage of 50% which was an input parameter of the simulation. The lower hackly line shows the values of the reference simulation. The curve decrease if a WLAN cell is left and increase as soon as a new cell is entered and the connection is re-established. However traversing several cells the throughput levels off close to the reachable throughput with 50% coverage. The difference is again due to the overhead of all involved protocols.

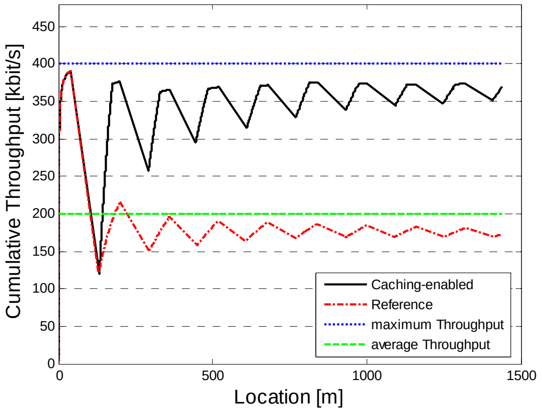

Figure 7 : Cumulative Throughput vs. Location

Contrary to that the curve of the smart caching enabled simulation reaches a much higher cumulative throughput which almost reaches the value of the optimal level. Packets which cannot be transmitted if the terminal is between two coverage areas are simply buffered and forwarded as soon as a WLAN connection is provided. Due to the larger bandwidth it is possible to transmit all stored packets on top of the usual traffic. The small gap between theoretical and final value of the simulation is caused by protocol overhead.

Which impact the coverage ratio has on the overall performance is shown in Figure 8. For ratios between 10% and 75% the cumulative throughput is depicted. Again due to references reasons the optimal limit is also included in the graph. It can be seen that even for a network coverage ratio of around 50% the overall throughput is only slightly below the optimal value if enough successive WLAN areas are traversed. But even at the beginning after entering the second WLAN cell the 50% curve comes close to the optimal value of 400 kbit/s. This implies that smart caching is most suitable for non-real-time services like multimedia streaming or prefetching of data in patchy or heterogeneous network environments.

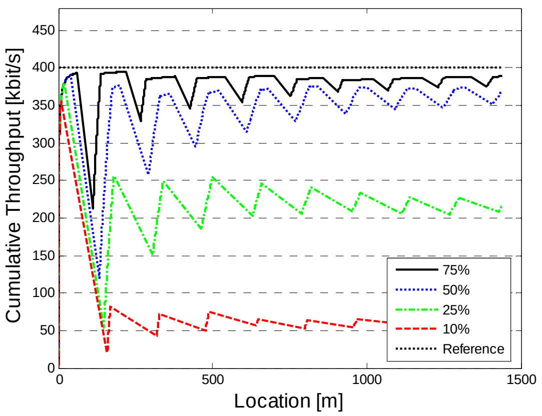

Figure 8 : Cumulative Throughput depending on Coverage Ratio

Relevant for streaming services is the amount of buffered data in the end device because it is an indication for the duration which the terminal can continue the service without having connection to the backbone. If the value is high enough the probability that the buffer is exhausted gets smaller and smaller so that the user will experience a continuous service although the connection was broken several times.

In Figure 9 the buffer size depending on the current position of the terminal is given. The lower curves represent reference simulations. Simulations were undergone for network coverage rates of 30 and 50%. As mentioned before the streaming rate and the consuming rate differ so that even in the reference simulations some packets could be stored in the end device to continue the service after leaving the cell. However the buffer is fast exhausted and the service is interrupted. Contrary to that the caching-enabled curves show that after entering the second WLAN cell the amount of buffered data dramatically raises so that even for a coverage of 30% almost the full idle gap between two cells might be bridged over. For a ratio of 50% it can be seen that the buffer size continuously increase the longer the simulation endures as the consummation in idle periods cannot exhaust the already buffered packets.

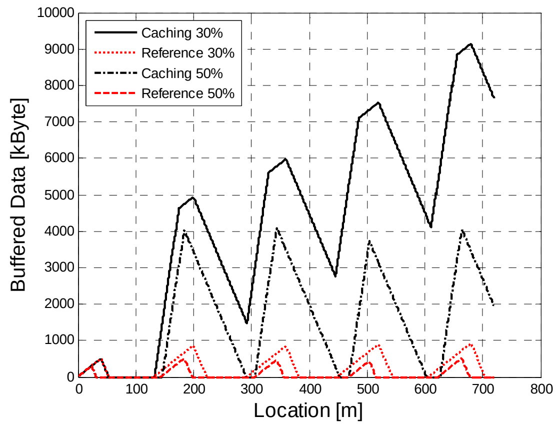

Figure 9 : Amount of buffered data in the end device

5.2. Analysis of Packet Delay

The prior results have shown that smart caching is capable of improving the network performance with respect to data rates significantly. However another criteria for user convenience is the perceived delay. The longer packets are delayed the longer the user has to wait for applications to start and services to be executed.

For the evaluation of the delay simulations with network coverage of 30, 50, and 75% are conducted. Again the corresponding reference simulations are depicted as well to show the performance gain of the smart caching-enabled architecture.

In Figure 10 the CDF of the packet delay is shown. It is evaluated the delay perceived by a terminal which is moving from AP 1 to AP 2. Further monitoring over several idle gaps between cells would not make sense as in the case of the reference scenario the delay would simply keep on growing and fudge the simulation results. This has nothing to do with reality as services after a lost connection would either be restarted or abandoned. Packets which are not received until the end of the simulation are treated with a maximum delay of the simulation time of 160 s.

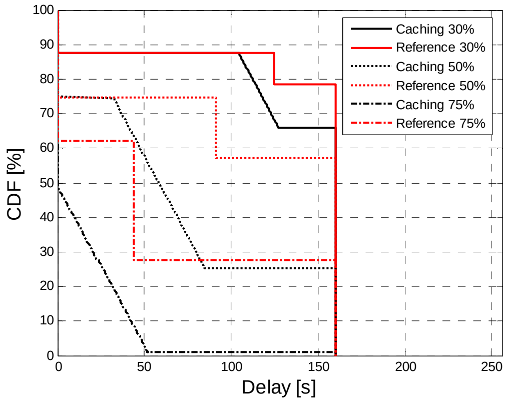

Figure 10 : Delay of Packets (CDF)

The reference simulations show that a certain amount of packets reaches the terminal with almost no delay. The next step in each curve represents packets which are received after re-entering the second cell. They have a longer delay as they were already issued while the terminal was in the idle gap. The height of the curve after the step corresponds to the coverage ratio. If e.g. only 30% of the scenario is covered it is obvious that more than 70% of them can not be received during the simulation. This value is again increased by protocol overhead. Therefore around 80% of the packets have a delay bigger than 160s as shown in Figure 10. The same applies for the other curves.

For smart caching-enabled simulations the delay is smaller for packets which are received while the terminal is in the second WLAN cell. As the packets are already stored in the CMP the delivery is much faster than in the reference scenario. For 75% coverage the values are much better than the reference curve and all packets are delivered during the simulation time so that the maximum value is decreased from 160 to around 50s. And 50% of the packets have even no bigger delay at all which is 15% smaller than the reference value.

6. Further Investigations

For the future it remains to further optimize the smart caching protocol. The establishment of sessions has to be improved and the identification of suitable CMPs has to be integrated. This should be possible by a stronger cooperation between the MobileIP and the smart caching protocol. If Caching Media Point and Mobility Anchor Point are collocated the discovery of the responsible CMP is already covered by the MAP association so that the mobility and the caching support are strongly cooperating. Also location updates of MIP might be used to restart the delivery of cached packets instead of actively requesting it by the client.

Also the WiFi standard should be adapted to nowadays available protocols. Transmission rates of 11 Mbit/s provided by the 802.11b standard are already outperformed by the 802.11a and g extension and also the WiMAX standard will provide rates of more than 50 Mbit/s. Such an increase in bandwidth on the wireless link will have major influence on the simulation results. However not the absolute bandwidth capacity of the different links but the relation between the capacity of the wireless and the wired links is the most relevant parameter.

7. Summary and Conclusion

Smart caching is a protocol which should support mobile users and their services in heterogeneous environments with all-IP networks. The coalescence of the different WiFi radio technologies and cellular networks will result in highly varying connection properties. On the one hand it requires a mobility support like MobileIP on the other hand it is most suitable to improve the network coverage and reliability. Including smart caching will allow a performance gain in such integrated heterogeneous networks. The paper has shown that both protocols perfectly fit together. A combination will allow an easy deployment and a fast migration from legacy systems.

The simulation results illustrate the performance enhancement due to the caching of packets close to the wireless link and the separation of the end-to-end connection. For non-real-time services a throughput close to a fully broadband coverage may be reached although only 50% of the area is actually illuminated by the different Access Points.

These results show that smart caching is a most promising protocol and network extensions. And the fusion of networks towards an all-IP solution will even boost the significance of this approach.

REFERENCES

[1] Solomon, J. "Mobile IP: The Internet Unplugged". Prentice Hall, Englewood Cliffs, 1998.

[2] Jung, Jaeyeon. "Proactive Web caching with cumulative prefetching for large multimedia data". Computer Networks 33, 2000.

[3] Goebbels, Stephan et al. "Intelligent Caching Strategy for Mobile Communication Networks". Proceedings of European Wireless 2004, Nicosia, Cyprus.

[4] Li, Jie and Chen, Hsiao-Hwa. "Mobility Support for IP-Based Networks". IEEE Communications Magazine, Vol. 43, No.10; Oct. 2005.

[5] Soliman, Hesham. "Mobile IPv6". Addison-Wesley, 2004.

[6] The Internet Engineering Task Force. "RFC 3775 Mobility Support in IPv6". www.ietf.org .

[7] Hsieh, Robert et al. "S-MIP: A Seamless Handoff Architecture for Mobile IP". Proceedings of INFOCOM, 2003.

[8] Aust, Stefan et al.. "Hierarchical Mobile IP NS-2 Extensions for Mobile Ad Hoc Networks". Proceedings of Wireless Networks and Emerging Technologies, 2004.

[9] NS-2, Network Simulator 2, Version 2.2.7, www.isi.edu/nsnam/ns/.