Evaluation of Mobility-Aware Personalized Services in Wireless Broadband Hotspots

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Abstract

In this paper we investigate the deployment of so-called Media Points to facilitate the provision of personalized services to mobile users within WLAN hotspots with fragmented coverage. An experimental evaluation was performed on the implemented demonstrator to determine the setup and resume times for a push session. The initial setup time for the considered service scenario, wherein 39.03 Mbytes of user data should be pre-cached, has been measured to be on average 6.3 seconds. After a temporary loss of connectivity, the average session resume time takes 2.8 s. The performance has been found to be primarily effected by three procedures, the WLAN Access Point association, the IP address assignment via DHCP and the data caching. Without modifications to WLAN, some potential performance improvements have been identified, e.g., the session setup and resume times can be decreased by approx. 0.5 s when coordinating the DHCP procedure with the WLAN Access Point association procedure.

INTRODUCTION

Since information and communication belong to the elementary needs of human beings by now, a further increase in demand – especially in the field of mobile Internet access – is to be expected. Present research aims at overcoming the scarcity of costly spectrum in 2G and 3G networks by sharing frequencies with other radio networks like DVB-T [1], [2] or by integrating short-range wireless technologies like Wireless Local Area Networks (WLANs).

Recent investigations have shown that the requirements on the provision of broadband push services to mobile users could be satisfied by a much more cost-effective broadband push system even in a fragmented radio coverage. However, delay-sensitive and conversational services like voice calls or videoconferences still have to be provided by cellular systems with full coverage like GSM or UMTS, since continuous radio connection is required during the service usage. But it is not necessary for Internet services such as e-mails, pre-selected (personalized) browsing, download of city information, pre-cached streaming audio, etc.

In [3] a concept for the integration of wireless broadband hotspots in the public cellular infrastructure to offer dedicated broadband push services is introduced. The wireless access is provided by so-called *Media Points*, which can be realized as regular WLAN Access Points attached on street lamps, traffic lights, public buildings, etc. and have typically a rather limited coverage area. In this paper we investigate the technical feasibility of the Media Point service concept for the delivery of personalized high-volume data for stationary or very-slowly moving users or terminals by means of state-of-the-art technologies. After introducing the Media Point network architecture and its signaling mechanism we describe the setup of our Media Point system demonstrator as well as the protocol and service implementation in detail. The system performance is discussed and the crucial factors are pointed out afterwards.

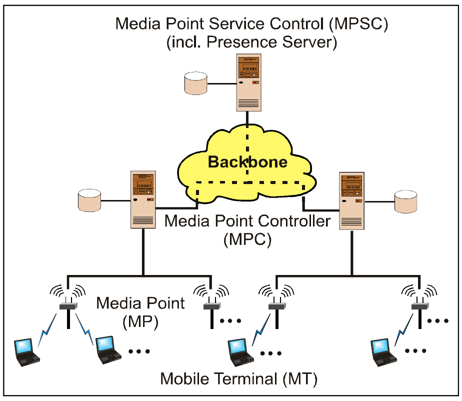

Figure 1. Media Point network architecture

THE MEDIA POINT NETWORK

Network Architecture

We consider the Media Point network architecture depicted in Fig. 1. The *Media Point Service Control (MPSC)* is a central entity, which monitors the presence status and location of each active user, and collects personalized user data from the Internet servers, e.g., from e-mail and content servers. MPSC maintains a database containing information of registered users (subscribers/customers) as well as their preferences and subscribed multimedia services. MPSC is connected via broadband Intra- or Internet to a number of *Media Point Controllers (MPCs)* with large cache capacity. Each MPC controls a group of *Access Points*, i.e., *Media Points (MPs)*, that are usually located in close geographical proximity and establish the broadband hotspots.

Signaling in Media Point Network

The Session Initiation Protocol (SIP) [4] is used for handling the mobility management [5] of each user's terminal and the signaling between the Media Point system components for session management and service provision. SIP has been standardized within the IETF as a norm for creation and termination of multimedia sessions. SIP is an application layer control protocol designed to be independent of lower layer transport protocols. Presently UDP is used as the default transport protocol but TCP is supported as well.

Within the SIP context each (mobile) user is uniquely identified by his or her global SIP address. The presence status of each user is stored in the so-called *Presence Server (PS)* [6]. MPSC subscribes for the user's presence status on a regular basis. PS notifies MPSC whenever the presence status of a subscribed user changes. On the other side, after the user or *Mobile Terminal (MT)* has entered a hotspot area and set up a connection with an MP (access point), MT registers itself at the controlling MPC, which in turn forwards the registration to PS. In this way PS knows the current presence status of the user and via which MPC the user can be contacted.

If any personalized data for the online user is available at MPSC, a new push session between MPSC and the corresponding MPC is initiated. The session is described with Session Description Protocol (SDP) [7]. After the session is established MPSC sends a list of the data that MPC can pull (download) and cache for the user. Instead of "true push" we apply the "smart pull" approach as it gives an MPC more flexibility on how and when the data should be downloaded depending on the capability of each MPC, e.g., cache/storage size, computational power, link quality, etc. For "smart pull" a list of available content is pushed to MT which in turn requests the transfer of data selectively. The session is terminated after all data has been pulled or after timeout. The identical SIP-controlled smart pull session is carried out between MPC and MT via the established wireless connection as well. Each time data has been pulled by MT an acknowledgment is sent back to both MPC and MPSC; the data can then be removed from their caches. In case that the session is interrupted, e.g., due to loss of wireless connectivity, MPC keeps the remaining data in its cache for a predetermined time. The session can be resumed by MT with the same MPC (e.g., via the same or another MP of the same group) or another MPC.

The strategy to pre-cache data in MPCs before it is pulled by MT becomes more advantageous when the link capacity between MPSC and MPCs is limited, e.g., due to high network load, and when the data can be cached in an MPC before the user has entered one of the controlled MP coverage zones. This requires sophisticated positioning methods that can be realized by integrating Media Points in public cellular networks.

MEDIA POINT SYSTEM DEMONSTRATOR

In order to prove the Media Point system concept and to evaluate the applicability and performance of existing technologies and standard protocols, we developed a Media Point system demonstrator, which is based on IEEE 802.11b WLAN. A personalized push service for multimedia contents such as video trailers or music files is implemented. SIP is used for controlling the push sessions and for monitoring the presence status of a mobile user (represented by a laptop equipped with a WLAN card) and his/her location.

UDP is used as transport protocol for the exchange of SIP messages. Before the SIP-based communication can take place, a WLAN connectivity between a user's mobile terminal (MT) and a MP must first be established, and an IP address must be assigned via DHCP (Dynamic Host Configuration Protocol) to MT afterwards. Hence, before the first bytes of personalized data can be pushed to MT, a certain time is needed for setting up the wireless link and initiating the corresponding session. This *session setup time* strongly depends on the parameters adjusted for the DHCP and the software implementation of the demonstrator. A certain delay also occurs when a running session is interrupted, e.g., due to lost MP coverage, and resumed at another MP, which is referred to as *session resume time*.

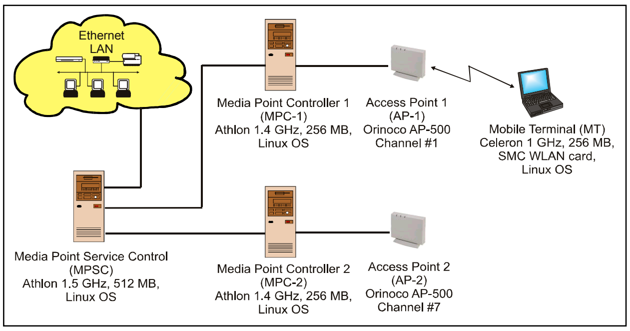

Figure 2. Media Point demonstrator setup

Demonstrator Setup

Fig. 2 shows the setup of our Media Point demonstrator. It consists of three PCs (i.e., two acting as MPCs and the other as MPSC), two IEEE 802.11b Access Points (APs), and a laptop (MT). The MPSC is connected via 100 Mbit/s Ethernet link to the local area network and to both MPCs, each of which controls a single AP. MPSC and MPCs build the Media Point core network with two hotspots. In order to avoid interferences both APs are configured to operate on different channels (in our case channel number 1 and 7).

Session Setup and Completion Procedure

Fig. 3 shows the message flow between the Media Point system components within the sub-procedures for setting up and completing a new data push session. In the following each sub-procedure is briefly described (according to its number assigned in the figure):

1. *Initial presence notification*: In order to be informed about presence status of a user (e.g., user *Alice*) the SIP User Agent (UA) of MPSC sends a SUBSCRIBE message to Presence Server (PS) which is co-located in MPSC. After acknowledging the message, PS responds with a NOTIFY message to indicate current presence status of the subscribed user. Each time the user's status changes MPSC's SIP UA is notified. If the user is online, the NOTIFY message includes the IP address of the MPC, via which the user can be contacted. A timeout can be given for a SUBSCRIBE message. In the demonstrator the timeout is set to unlimited.
2. *AP association and IP address assignment*: Each active AP broadcasts periodically a beacon frame consisting of information about the WLAN cell and other communication parameter. When a mobile terminal (MT) enters the coverage area of an AP and detects its beacon frame, an association procedure will be performed. Thereafter an IP address is assigned to MT temporarily by the DHCP server installed in the MPC, with which the AP is connected (i.e., AP-1 with MPC-1, AP-2 with MPC-2). The IP address is refreshed periodically. Finally, the MPC's IP address is forwarded by the DHCP client (of the user's terminal) to the user application (SIP UA).
3. *User registration*: MT (its SIP UA) periodically sends every 120 seconds a REGISTER message to PS via the MPC to update or refresh its presence status. After detecting a change in user's presence information, PS sends a NOTIFY message to MPSC's SIP UA (in general to all SIP User Agents that have subscribed for this particular user).
4. *MPC push session initiation*: When new personalized data for an online user "arrive" at MPSC, a push session between MPSC and MPC is started. MPSC initiates it by sending an INVITE message to MPC. After the session is created, MPSC sends a MESSAGE message to MPC including the URLs (Uniform Resource Locators) where MPC can download[1] the data by itself via HTTP. Together with the download-URL the number of data files available is included in the body of MESSAGE[2].
5. *User data caching in MPC*: By using the GNU *wget* tool (wget.sunsite.dk) MPC downloads all (new) data from MPSC. Each time a data file has been downloaded completely, an acknowledgment is sent to MPSC (using the MESSAGE method).
6. *MPC push session termination*: After MPSC has recognized that MPC has downloaded all the personalized data available for a particular online user, the push session is terminated by means of BYE method.
7. *Terminal push session initiation*: After all the user data is cached in MPC, a push session with MT (if the user is still online) is initiated. The subsequent actions are similar as described for sub-procedure 4.
8. *User data download*: This sub-procedure is similar to the sub-procedure 5 described before. The difference is only that it is now carried out between MPC and MT.
9. *Download acknowledgment*: After each data file download is acknowledged by MT, MPC sends again an acknowledgment to MPSC to allow it delete the data from its database.
10. *Terminal push session termination*: This sub-procedure terminates the push session between MPC and MT (similar to sub-procedure 6).

The *session setup time* is defined as the time span between the beginning of AP association procedure and the point of time where MT is able to download the first data segment from MPC. Hence it comprises the sub-procedures 2 to 7, since sub-procedure 1 can be performed at any point in time before. Obviously the time needed for completing sub-procedure 5 (data caching in MPC) strongly depends on the amount of media data available.

A "smart pull" session between MPC and MT might be interrupted due to lost connectivity with AP, for example. In order to resume the session at another AP (or at the same AP) which is still controlled by the same MPC, sub-procedures 2 and 3 must be repeated (assumed that the data is still cached in MPC). If no new data is available in MPSC, the session continues with sub-procedure 7. The *session resume time* is therefore defined as the time span comprising sub-procedures 2, 3 and 7. It should be differentiated whether the session is resumed at an AP controlled by the same MPC (*intra MPC*) or by a different MPC (*inter MPC*). In the latter case the sub-procedures 4, 5 and 6 must be carried out as well, since none of the data has been cached in the new MPC yet. It differs only from initial session setup procedure in the fact that most probably not all data must be cached in MPC since some data portions might have been transferred to MT prior to session interruption.

[1] Note that the "smart pull" approach is used for the push service.

[2] The SIP MESSAGE method is usually used for instant messaging purposes.

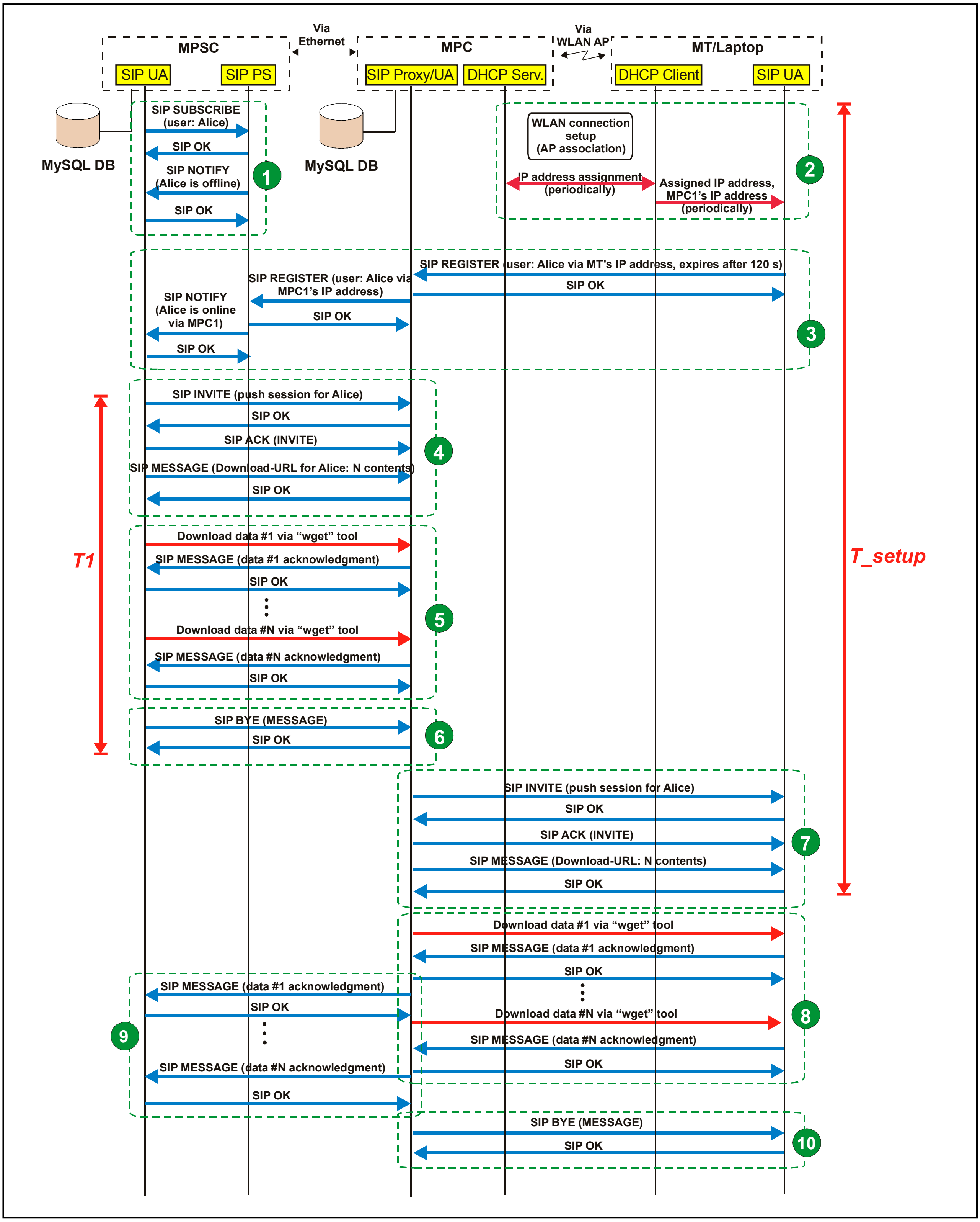

Figure 3. Setup and completion of a SIP-controlled data push session

PERFORMANCE EVALUATION

The main goal of the performance evaluation using the Media Point system demonstrator is to determine the times needed to set up a new data push session and to resume interrupted sessions due to lost AP connectivity. The focus is thus given to the time behavior in particular sub-procedures, which influence the setup and resume times at most.

Evaluation Methods and Conditions

The experimental evaluation is carried out with a stationary user's terminal (laptop) and under the condition of an optimal wireless link quality (net data rate ~500 kbyte/s) between the terminal's WLAN card and the APs. There is no cross traffic induced by other users and co-channel interference can be excluded. The network protocol analyzer *ethereal v. 0.9.7* (www.ethereal.com) is used to trace the IP packet traffic between the Media Point system components.

In order to obtain accurate time measurements, the system clocks of MPSC, MPCs and MT have been synchronized to the system clock of a reference machine (within the LAN). Due to delays on the transmission cable, for example, absolutely synchronized times (precision less than one second) of the Media Point components is hardly to achieve. Hence, some time measurements must be based on estimations, e.g., based on user's perception or amount of transmitted data. In general the average time values, which are based on at least five independent measurements (up to ten trials for crucial processes), are used as evaluation results.

The following scenario was used for the measurements: the user has subscribed to data services like a song hit list and announcements of movie trailers. During the test session he/she receives one MP3 song file and one movie trailer. In total this results in a data amount of 39.03 Mbytes.

Results

The time needed to complete each sub-procedure is ascertained on the demonstrator and the results are summarized in Tab. 1. The total amount of IP data which is exchanged between the components during each sub-procedure is indicated, wherein the portion of data transmitted across the air interface is indicated within parenthesis. Some remarks should be mentioned here:

- The elapsed time during sub-procedure 1 is not relevant for the evaluation since the SIP Presence Server and User Agent are co-located in the same machine (MPSC).
- The total data amount during sub-procedure 2 only considers the exchanged messages during the DHCP procedure. In contrast the duration in seconds also comprises the AP association.
- The total data amount being cached in MPC only comprises the personalized data (payload); the signaling data is negligible.

Table 1. Durations and total data amount of each procedure

No.	Description	Duration [s]	Total data (air i/f) [bytes]
1.	Initial presence notification	n/a	250 (0)
2.	AP assoc. + IP addr. assign.	2.6	1322 (1322)
3.	User registration	0.05	2024 (639)
4.	MPC push session init.	0.04	1851 (0)
5.	User data caching in MPC	3.45	39.03 M (0)
6.	MPC push session termin.	0.013	548 (0)
7.	Terminal push session init.	0.27	1870 (1870)
8.	User data download	72.11	39.03 M (39.03 M)
9.	Download acknowledgment	0.005	604 (0)
10.	Terminal push session term.	0.073	570 (570)
(Initial) Session Setup Time		6.3	(3831)
Intra MPC Session Resume Time		2.8	(3831)
Inter MPC Session Resume Time		2.8 … 6.3	(3831)

The session setup time is the amount of time needed to establish a new data push session between MT and an MPC (via an AP). As indicated in Fig. 3, all the personalized data available in MPSC must first be cached in the corresponding MPC, before MT can "pull" the data from MPC. The session setup ends with the completion of sub-procedure 7. Assumed that two independent data files, which amount to 39.03 Mbytes together, should be downloaded, an average session setup time (T_setup) of 6.3 seconds is ascertained, wherein

$$T\_setup = f(data\ amount).$$

Approximately 3.0 seconds of the setup time (i.e., 47% of 6.3 seconds) do not depend on the amount of data cached during the session and are more or less constant (sub-procedures 2, 3, 4, 6 and 7). We have observed that the pure SIP signaling mechanisms, i.e., exchange of SIP messages in sub-procedures 3, 4, 6, 7, 9 and 10, only have a minor impact on the overall system performance.

An interrupted session might be resumed at the same or at a new AP/MPC. In case of *intra MPC session resume*, sub-procedures 4 to 6, which complete after $T1$, need not be performed anymore, assumed that all the personalized user data were already cached in MPC during one of the previous sessions. The intra MPC resume time ($T\_res,intra$) is thus mainly influenced by AP association and DHCP procedure times and averages to 2.8 seconds since

$$T\_res,intra = T\_setup - T1 \neq f(data\ amount).$$

In case of *inter MPC session resume*, since none of the user data has been cached in the new MPC during a previous session yet, sub-procedures 4, 5 and 6 must still be carried out between MPSC and the new MPC. The time needed for sub-procedure 5 depends on the amount of data the user still has to download (it corresponds to all the data still cached in MPSC). Hence the inter MPC resume time ($T\_res,inter$) averages roughly between $T\_res,intra$ and T_setup, thus

$$T\_res,intra < T\_res,inter = f(data\ amount) < T\_setup.$$

Note that for both inter and intra MPC session resume the same DHCP procedure is assumed, i.e., it always begins with broadcasting a DISCOVER message to reach any DHCP server. It might be possible to configure the DHCP client in such a way that, if it loses connection to a DHCP server, it attempts requesting an IP address from the last connected DHCP server for a certain time (by sending a REQUEST message periodically), before broadcasting a DISCOVER message to search for other DHCP servers (i.e., DHCP server at another MPC). In case of intra MPC session resume this retry approach might save the time for performing DHCP server discovery (approx. 0.45 seconds in average). In a real Media Point scenario where probably a number of access points, which are geographically located in proximity, are controlled by the same MPC, such retry approach could be advantageous. The number of retrials must be optimized in accordance with the Media Point network infrastructure and the user's and terminal's mobility behavior.

CONCLUSIONS

In this paper the Media Point service concept to deliver high-volume personalized data to mobile users within WLAN hotspots is briefly described. A system demonstrator has been developed in order to show the technical feasibility of the concept by means of state-of-the-art technologies. The subsequent experimental performance evaluation aims to determine the amounts of time needed to set up a new session or to resume an interrupted push session.

The results have shown that the sub-procedures for setting up a connection between a user's WLAN terminal and an Access Point (AP) together with the subsequent assignment of a temporary IP address via DHCP strongly impact the resulting session setup and resume times. An average time of around 1.6 seconds (minimum: 0.5 s, maximum: 2.5 s) is observed on establishing a wireless connectivity between mobile terminal and AP. Activated built-in WLAN security protocols do not increase the setup time significantly. There is no possibility to reduce this AP association time without the modification of IEEE 802.11 standard.

The evaluation has also shown that the mechanism for controlling the sessions by means of SIP have only a minor impact on the overall system performance. By optimizing the own implementations of SIP User Agents in MPSC, MPC and terminal, only a minor system improvement can be expected, as far as the demonstrator environment is concerned. However it must be further investigated whether a significant improvement could be achieved when an extended Media Point scenario with much more simultaneous mobile users is considered.

As in the current implementation the initial session setup comprises the caching procedure between MPSC and the corresponding MPC, the setup time increases in line with the amount of user data. In general, an intelligent pre-caching mechanism for high-volume personalized user data in MPC, e.g., by caching the data in MPC before the user tries to set up a link with an AP, is essential for the performance improvement. In this way the variable session setup time (due to different data amounts) can be replaced by the (fixed) session resume time of about 2.8 seconds in average.

Finally, it has to be mentioned that the scalability issue has not been thoroughly investigated yet. Higher number of simultaneous users might strongly impact the performance of the core network components (MPSC, MPC, AP) since higher processing latencies, e.g., for database queries, are expected. In addition, lower throughput on the air interface due to channel sharing among terminals, that are served by the same AP, certainly extends the transmission delays during signaling and data download procedures. In a real scenario, further degradation of the system performance can also be expected due to spectral interferences with the same or different wireless systems. All of these issues are subjects for further study.

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