Incorporating Proxy Services into Wide Area Cellular IP Networks

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Abstract— **Performance enhancing proxies have drawn considerable interests from the network community as an effective approach to improve user experience in cellular networks. Previous research on this subject has been focusing on the design of proxy servers as well as the functions that these servers provide. In this paper, we study the placement of proxy servers, especially the approach of incorporating proxies into cellular networks, which allows better, faster, and more secure proxy services. We discuss various factors that must be considered when placing proxies inside cellular networks, including the information requirements of the proxies, the network requirements for supporting the proxy functions, and mobility management. Using GPRS as an example, we lay out a procedure for adding proxies into data transmission path in cellular networks.**

I. Introduction

In recent years, wireless communication has also become an indispensable part of many people's daily life, but often in the simple forms of cellular phones or pagers. With the development of the 3rd generation wireless networks (3G), which promises higher speed and more convenient data access, wireless data services are expected to gain popularity very rapidly and become more sophisticated. Future wireless data services will allow mobile users to access the Internet or data in their home/office whenever and wherever they need, and using whatever devices they prefer.

In the mean time, many challenges remain ahead as to how to realize true ubiquitous computing with high efficiency over wireless data networks. One of these challenges is that most of the existing protocols and applications on the Internet are designed for wired networks. As a result, many of them do not work properly or efficiently on wireless networks where radio channels have different characteristics and devices vary greatly in size and capability. A popular approach for solving this problem is to make use of performance enhancing proxies [4], [16]. In this case, mobile users communicate with the performance enhancing proxies which in turn exchange information with the destination servers on behalf of the mobile users. At the proxy, information from the original server is converted to make it suitable for the wireless environment, while at the same time taking into account of user's preference and the characteristics of the device in use. Take Web browsing as an example. Proxies can reorganize the layout of web pages and shrink images to fit into the small display of PDA devices. Performance enhancing proxies can also perform channel adaptation for certain applications, such as audio and video streaming, to further improve their performance. [6], [13], [14].

A. Why proxies within cellular IP networks?

Figure 1 depicts the general architecture of a wide area cellular network connected to the public Internet. For simplicity, we assume the entire cellular network is IP-based[1]. The cellular IP network consists of three key components: gateway routers, access routers, and base stations. Base stations communicate directly with mobile terminals via wireless links. A number of closely located base stations may form a subnet and are connected to the rest of the cellular network through an access router. Gateway routers serve as bridges between the cellular IP network and the Internet backbone. Packets from an Internet server to a mobile user travel through the public Internet and enter the cellular network via a gateway router. Once in the cellular network, they are routed to an appropriate access router, then to the base station that are serving the mobile station (MS), and finally to the mobile station via wireless links.

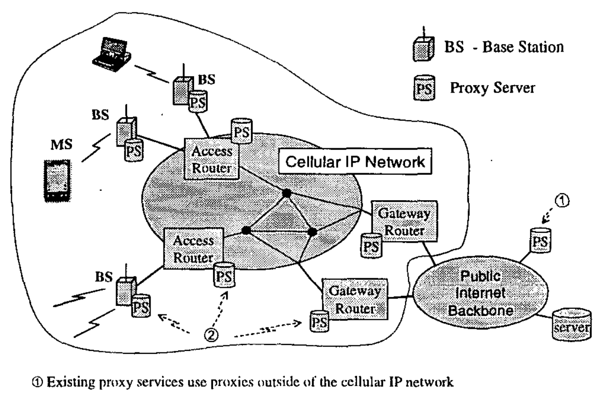

Fig. 1. General architecture of a cellular IP network with proxy servers.

Currently, there are already a variety of proxy services commercially available that are tailored specifically for certain wireless devices or access networks. However, as will be described in section 2, all the existing services place proxy servers outside wireless networks (indicated by the

[1]Ideas presented in this paper are still valid even if the network is not entirely IP-based.

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proxy marked with 1 in Figure 1). With this approach, because the proxies are located outside the wireless network, the performance is often compromised by the long latency between mobile user, proxy server, and original data server. In addition, proxies outside wireless networks have only limited access to information about the networks and the users due to security concern and non-existence of convenient interfaces to wireless networks, thus limiting their ability to perform many functions efficiently. If channel adaptation is needed, the amount of traffic generated for updating channel state can also be significant, thus increasing the likelihood of network congestion.

In light of the high latency, traffic overhead, and security problem in the existing proxy service model, a clear alternative is to bring the proxy servers closer to the mobile users by placing them inside the cellular network (indicated by the proxies marked with 2 in Figure 1). In this case, proxies have easier access to information regarding wireless links and users' service profiles, and the wireless network no longer needs to send any sensitive information outside its network, resulting in better, faster, and more secure proxy services. In this paper, we address issues that need to be considered when incorporating performance enhancing proxies into wide area wireless IP networks, and discuss the pros and cons of several different approaches.

The rest of the paper is organized as follows. In Section 2, we summarize various performance-enhancing proxy functions that may be implemented for wireless data users. In Section 3, we discuss several key issues that must be considered in order to incorporate proxy servers into a general wireless IP network. The problem is examined from the perspective of both proxies and networks. Using GPRS (General Packet Radio Service) as an example, in Section 4, we demonstrate in detail the potential approaches to add proxy capabilities into cellular networks, followed by the conclusion in Section 5.

II. Proxy functions and existing proxy services

A. *Proxy functions for wireless data users*

Table I lists various proxy functions that can be used to improve the experience of mobile users in cellular wireless networks. Some of these functions operate at the application level, so the proxy servers need to understand the context of specific applications; others operate at the transport layer or below and only need to deal with individual packets, without knowledge of how the applications work [4].

At the application level, Caching and prefetching are two basic mechanisms for reducing access latency [1], [8]. Content transformation covers a broad range of operations that proxies may perform. The key idea is to convert data to a format that is more suitable to the mobile user, based on information such as device characteristics, link conditions, and QoS requirements [3], [10], [12]. For example, content transformation for images and video involves operations such as reducing image size and color depth, removing high frequency information, or transcoding which is to encode images/video frames with another coding scheme. It is often desirable to make content transformation adaptive to channel conditions to achieve the best possible quality for a given channel. Another type of application level proxy function, application level protocol translation, allows devices and servers that do not support a common protocol to exchange information through the proxy server. For instance, when a user wants to access web servers through a cell phone, proxies can translate web pages written in HTML to languages such as WML, so that data can be displayed properly.

TABLE I
Performance enhancing proxy functions for wide area wireless networks.

Application Proxy	Data Application	caching, prefetching
		content transformation (e.g. customization, adaptation, compression)
	Multimedia Application	application protocol translation (e.g. HTML<->HDML)
Transport Proxy		protocol translation (e.g. TCP<->WTP, UDP<->WDP)
		TCP performance enhancement (e.g. split connection, snoop protocol)
		compression (payload and header compression), header suppression

Due to the widespread use of TCP on the Internet, most of the proxy functions at the transport and network layer are targeted at the TCP/IP protocols. Many proxy functions have been proposed to improve the performance of TCP over slow and lossy wireless links [2]. Additionally, payload or TCP/IP header compression may be applied to individual packets to reduce the amount of traffic over cellular links [4], [5], [7].

B. *Existing and forthcoming wireless data services*

Commercial services that are tailored specifically to wireless network users have started to emerge for the past few years. They range from simply enabling wireless data access, to more sophisticated ones that can convert regular Web pages to formats that are more suitable to mobile environments. Table II lists several such services together with the functions they provide.

TABLE II
Key functions of existing and forthcoming proxy services.

Services	Primary Functions
AT&T PocketNet	Protocol translation for cell phones
Project Panama	Markup language translation for a variety of devices
Proxinet	General content transformation for Palm Pilot
GoAmerica	Data compression for CDPD users
MobilLogic & Wireless Knowledge	Compression, simple content trasformation, mobile-optimization for MS-exchange servers

Existing proxy services rely on proxies outside of cellular networks and have no adaptation. To add in adaptation support, the existing service model becomes less attractive because of the latency, traffic overhead, and security problems described previously. In the rest of this paper, we discuss a more efficient approach which places proxies inside wireless networks.

III. Design considerations for placing proxies into cellular IP networks

A number of issues need to be considered when incorporating proxy services inside the cellular IP network shown in Figure 1. Many of these issues depend heavily on where the proxy services are located. There are two different aspects regarding the location of a proxy server. The first is its physical location in terms of the distance from the proxy to other key components of the network. Specifically, inside a cellular IP network, proxy servers can be placed (1) close to a gateway router where there are likely to be a high concentration of traffic, (2) close to an access router where traffic from a number of base stations in its subnet is aggregated, or (3) close to a base station which only handles traffic for a single cell. The second aspect of the location refers to the location of the proxy on the routing path between a base station and a gateway router. Specifically, a proxy server may be accessed between a gateway router and an access router, or between an access router and a base station, as illustrated in Figure 2. Three routes which include proxies on the data path are highlighted in the figure. Note that Figure 2 does not represent the actual physical locations of the proxies. For instance, the proxy between the base station and the access router on route (1) in the figure can be physically close to or even co-located with either of them.

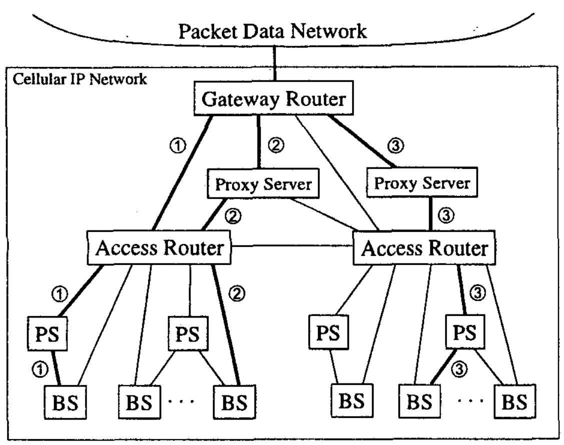

Fig. 2. Illustration of locations of proxies on the routing path between base station and gateway router.

A proxy server may support one or multiple proxy functions. Different proxy functions may be placed at different proxy servers depending on the application requirements, network and server capacity, and mobility, etc. We discuss the impact of these factors on proxy placement in the rest of this section.

A. Information required to support proxy functions

In order to support the proxy functions described in section 2 efficiently, proxy servers need to obtain current information about the cellular network where the proxy services are offered, as well as the requirements and characteristics of mobile users. Specifically, proxy servers may need to know what commitments that the mobile network has made in terms of service quality (e.g. user's QoS profile), what network performance can currently be supported by the network (e.g. current channel conditions), what users actually need for their current applications (e.g. application requirements and user preference), what environment they are in (e.g. location information), and what functions the devices can support (e.g. device capabilities). Other information such as billing method may also affect the transformation decision. For instance, users paying by bytes are likely to be more conservative in using the bandwidth than those paying at flat rates.

To determine the best location for a proxy function, we need to consider whether the information needed for performing the function can be obtained conveniently. In general, by placing proxies within the cellular network, they should be able to get more complete information at a faster speed than proxy servers outside of the network. However, the exact location, namely whether it is close to the base station, the access router, or the gateway router, can still make a big difference in some cases. If prompt reaction to channel condition changes is required by the application, such as adaptive video transmission, the location of the proxy function must be chosen such that the speed of obtaining channel conditions is adequate for achieving the desired performance.

Some functions work more efficiently when located at certain places due to the nature of the functions. For example, if IP header compression is done at a gateway or an access router, the modified packets will need to be encapsulated before being sent to a base station and then de-capsulated before being delivered over the air, whereas the system would be much more efficient if compression is done at base stations.

B. Network and server requirements for supporting proxy functions

An issue related to information requirements of proxies is the amount of traffic generated from exchanging information between a proxy server and other components of the network in order to support the proxy functions. Some information, such as device characteristics, normally does not change within one session, thus only needs to be obtained once for each session. Others, especially channel conditions, may require continuous monitoring and frequent updates. Moreover, depending on the requirements of individual applications, information update may be needed at different frequencies. In general, relatively long time averaging of link throughput may be sufficient for most data applications, while multimedia applications might require frequent update on detailed channel conditions.

As far as channel information is concerned, the base station is the best location to obtain such information, while placing proxies close to gateway routers introduces the largest amount of traffic across the network.

In addition to network capacity, proxy server capacity and scalability also need to be considered for the placement of proxy functions in a cellular mobile network. The more users a proxy server has to support, the more powerful it must be, to avoid becoming a performance bottleneck of the system. The scalability issue of a web transcoding service is studied in [10].

C. Impact of user mobility

The mobility of a user in cellular networks can trigger location update in the system, so that future packets for the user can be delivered correctly. When proxy servers are added into the cellular IP network, they may also need to be updated with the new location during a mobile hand-off. The final decision depends on the location of the proxy server on the routing path between the base station and the gateway router as illustrated in Figure 2, as well as certain characteristics of the proxy function. Table III summarizes whether a proxy should be informed of the cell change in various hand-off scenarios. It turns out that, as shown in Table III, a proxy may not need to be informed of the cell change only if all of the following three conditions hold: (1) the CoA (care of address) of the mobile station is the access router, (2) the proxy is accessed between the access router and the gateway router, and (3) the cell change is within the coverage area of the same access router. However, if any base station specific information is required by the proxy function, location update becomes necessary, even if all three conditions described above are met, so that the proxy can continue to obtain the information from the new base station.

TABLE III

PROXY UPDATE REQUIREMENT FOR DIFFERENT PROXY LOCATIONS, SELECTIONS OF CoA, AND TYPES OF CELL CHANGE.

	Intra-AR Service Area Cell Change		Inter-AR Service Area Cell Change	
Proxy Location / CoA	Between BS and AR	Between AR and GR	Between BS and AR	Between AR and GR
Base-Station	Yes	Yes	Yes	Yes
Access Router	Yes	No	Yes	Yes

BS - Base Station, AR - Access Router, GR - Gateway Router

Just like a user might move to the service area of different access routers during a session, at some point, a user might move out of the service area of a proxy server. The proxy server then needs to forward the entire session profile, including information for performing various proxy functions as well as the status of the on-going transactions, to the new proxy so that the new proxy may continue to provide the same service to the user. The related routers must also be updated so that future packets can be delivered to the new proxy server. Section 4 will present a detailed call flow of this procedure in the context of GPRS (General Packet Radio Service).

To transfer the session profile from one proxy server to another may introduce substantial delay and overhead to the hand-off procedure. The proxy functions must be carefully designed to carry out the transition efficiently. Clearly, the closer the proxy is associated with individual base stations, the more likely that such transitions may occur. The placement of the proxy functions must take into consideration of the overhead involved with mobility update procedures.

D. Location of the proxy functions

The discussions above show that the placement of a proxy function should consider the information requirements of the proxy function, its bandwidth and processing requirements, as well as mobility management. If a proxy is placed close to the gateway router, it has to be powerful enough to handle the high concentration of traffic from all the base stations it covers. Because of the relatively long distance to individual cells, it is not convenient to collect and react to channel condition changes from such proxies. On the other hand, since a mobile user will remain in the coverage area of the proxy within one session despite handoffs, there is no need of moving the status of proxy functions to another proxy. If a proxy is placed close to the access router, it has relatively easier access to the device and channel information. However, the status of the proxy functions may need to be transferred when a user moves to the coverage area of another access router to avoid triangular routing. Such proxies may still not be close enough to base stations to react promptly to fast changing channel conditions, which can be a problem for some real-time applications. Proxies close to base stations enjoy most convenient access to the channel information. However, only functions with small execution footprints may be placed here, as inter-cell hand-offs may frequently require current proxy session states to be moved to another proxy.

Other issues, such as service discovery, security, reliability, and cost also play a role in determining where a proxy should be placed. Detail discussions on these issues are beyond the scope of this paper. Having studied how to determine the appropriate locations for different proxies, we lay out detail procedures for incorporating proxies into a GPRS network in the next section.

IV. Incorporating proxies into GPRS networks

General packet radio service (GPRS) is a new packet data service introduced in the GSM phase 2 standard [17]. It consists of a packet wireless access network and an IP-based backbone. The GPRS wireless access network can offer a wide range of payload bit rates depending on the wireless access technology deployed and the terminal capabilities. With the increased link capacity, a larger range of applications and devices may be supported. Proxies will play an important role in fulfilling a wide variety of user's needs. In this section, we use GPRS as an example to illustrate how to incorporate performance enhancing proxies into cellular IP networks.

Figure 3 shows the logical architecture of GPRS. Two important network entities are the Serving GPRS Support Node (SGSN) and the Gateway GPRS Support Node (GGSN). SGSN and GGSN correspond to the access router and gateway router in the general wireless IP network shown in Figure 1 respectively. In the following, we describe briefly of the GPRS components that may be affected by adding proxy severs[2].

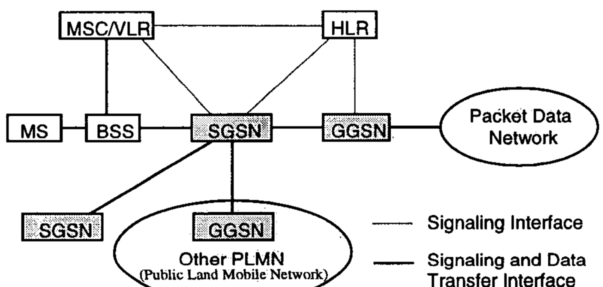

Fig. 3. GPRS Logical Architecture.

A. *GPRS overview*

In GPRS, SGSN keeps track of the locations of individual MSs and performs security functions as well as access control. GGSN, which is connected with SGSNs via an IP-based GPRS backbone network, provides interworking with external packet-switched networks. GGSN contains the routing information to the point of SGSN for the current GPRS users, which means in mobility management, the CoA of an MS is the address of its SGSN. The interface between SGSN and MSC/VLR (Mobile Service Center/Visitor Location Register) (Figure 3) is to enable MSC/VLR to send voice paging messages to SGSN, and to have SGSN page the users if users subscribe to both GPRS and GSM services. The interface between GGSN and HLR (Home Location Register) is for the GGSN to request subscribers location information from the HLR if needed.

[2]GPRS functions that are not directly related to proxy service are simplified in our discussion. Please refer to [17] for a complete description of GPRS.

1) PDP context

An important concept in GPRS is called PDP (Packet Data Protocol) context. The PDP contexts at SGSN and GGSN, which are established during the PDP context activation process, contain routing information for forwarding packets between GGSN and MS, and between SGSN and public data network respectively. PDP context activation can be initiated by MS or by the network. When an MS wants to activate access to the public data network, it needs to inform the network to activate a PDP context. Figure 4 illustrates the corresponding PDP context activation procedure. Basically, the MS sends a PDP context activation request to the SGSN, which then sends a Create PDP Context Request to the affected GGSN. After processing the request, the GGSN creates a PDP context for this flow and replies with a Create PDP Context Response message to the SGSN. The SGSN then finishes the creation of its copy of PDP context and returns an Activate PDP Context Accept message to the MS if the request succeeds.

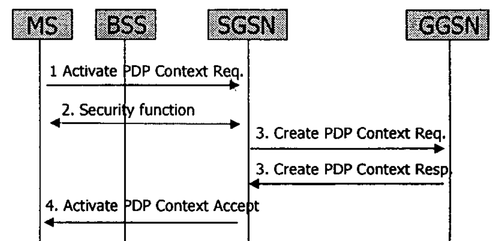

Fig. 4. PDP context activation procedure.

2) Mobility management

GPRS has a comprehensive mobility management scheme. A major part of it deals with the routing area update during a cell change. When a GPRS-attached MS enters a new cell, if it remains in the service area of the same SGSN, then only the SGSN is updated. Otherwise, in addition to SGSN, the PDP context at the GGSN is also updated. Figure 5 shows the step by step procedure of an inter-SGSN routing area update.

The inter-SGSN routing area update proceeds as follows. When an MS detects that it is in a new routing area, it starts the routing area update procedure by sending a Routing Area Update Request to the new SGSN (step 1). The new SGSN then requests for the MS state information and data packets from the old SGSN (step 2-5), so that it may continue forwarding packets to the MS. In addition, location information is updated (step 6-10).

The routing area update request may be rejected in the middle of the procedure due to regional subscription or roaming restrictions. A reject is returned to the MS with an appropriate cause. Cell changes may also trigger update of MSC/VLR. The procedure is very similar to the one described above. We will not repeat the details here.

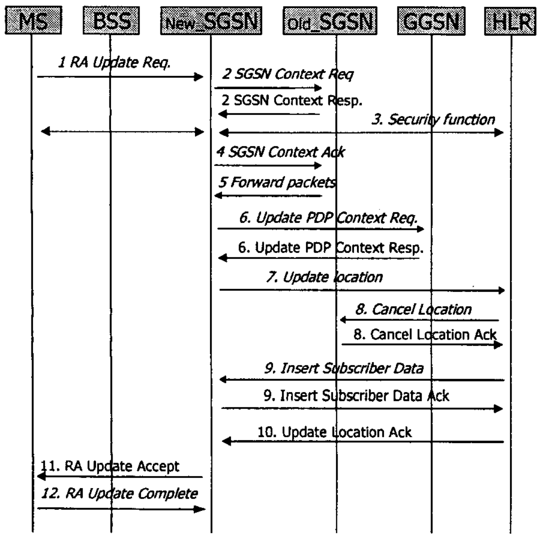

Fig. 5. Inter-SGSN routing area update procedure.

B. *Adding proxies to GPRS*

In principle, proxies may be placed close to base stations, access routers, or gateway routers. However, since base stations are not IP capable in the current GPRS, it is very difficult to place proxy functions at base stations or between base station and SGSN without any major modifications to the GPRS architecture. In the rest of this section, we focus on how to support proxy functions between SGSN and GGSN with minor modifications to the GPRS architecture.

When a proxy function is located between an SGSN and a GGSN, from the SGSN's point of view, the proxy server acts similarly to a GGSN; while from the GGSN's point of view, it acts like an SGSN. The main GPRS components that may be affected by adding proxy servers are routing, which is controlled by PDP context, and mobility management. We now discuss these two issues as follows.

1) PDP context and routing

In GPRS, several PDP contexts may be created for a single MS to support flows with different QoS requirements. As described previously, the PDP contexts at SGSN and GGSN contain routing information for forwarding packets between the two. To support proxies between SGSN and GGSN, the scope of the PDP context needs to be slightly expanded to allow packets to be forwarded to entities other than SGSN and GGSN. In particular, for flows that need to go through a particular proxy, a PDP context may be created so that the corresponding SGSN and GGSN will send packets to the proxy server instead of to each other directly. In addition, the proxy server also creates a copy of the PDP context during the PDP context activation procedure, which contains the addresses of the SGSN and GGSN that are serving the mobile station. After processing the data, the proxy will forward the resulting packets to either the GGSN for outgoing packets or the SGSN for incoming packets. Figure 6 illustrates the modified PDP context creation procedure for supporting proxy server. The only difference from the standard procedure shown in Figure 4 is that the SGSN sends an Activate Proxy Request to the proxy server which in turn sends a Create PDP Context Request to GGSN. The responses follow the same path, namely from GGSN to proxy and then to SGSN. The address of the proxy server is either given in the Activate PDP Context Request from the mobile station (non-transparent mode), or determined by SGSN based on the type of flow the PDP context is going to support (transparent mode), as described in section 3.5.

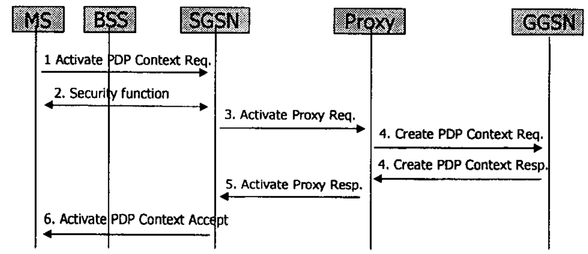

Fig. 6. PDP context activation procedure with proxy supports.

2) Mobility update

The mobility update procedure also needs to be changed accordingly. With proxies between SGSNs and GGSNs, there are three levels of mobility update (1) intra-SGSN, hence intra-proxy, (2) inter-SGSN, but intra-proxy, and (3) inter-SGSN and inter-proxy. The first scenario is the simplest, in which the MS stays within the service area of an SGSN after a cell change. The proxy does not need to be informed unless the proxy function requires information that is specific to the base station. If, as the result of a cell change, the MS has just moved into the service area of another SGSN but is still covered by the same proxy server (scenario 2), the proxy server should be informed about the change. The mobility update procedure in this case is very similar to that shown in Figure 5 except for Step 6. Instead of updating the PDP context at GGSN, Step 6 should update the proxy context at the proxy server. The most complex scenario of mobility update occurs when the MS moves out of the service areas of both SGSN and proxy (scenario 3). The mobility update procedure for this case is depicted in Figure 7. Step 1-5 and 7-12, which involve updating SGSN and HLR, are very similar to that shown in Figure 5. We will not repeat them here. Instead, we will focus on the steps related to the proxy only (Step 6.1-6.7). Once it is discovered that the MS has moved into the service area of a new proxy server, SGSN sends a Proxy Context Request to the new proxy. The proxy discovery is carried out by SGSN for transparent proxy services, or by MS for non-transparent proxy services. In the latter case, the MS will include information regarding the new proxy server in its Routing Area Update message to SGSN (Step 1). Upon receiving the Proxy Context Request, the old proxy responds with a Proxy Context Response message which includes configuration information for the proxy functions, execution status, PDP context, etc. The new proxy returns a proxy Context Acknowledgment message to the old proxy, which then starts to tunnel the buffered or new packets to the new proxy. The new proxy sends GGSN an Update PDP Context Request with the address of the new proxy. The GGSN updates its PDP context fields and returns an Update PDP Context Response message. The new proxy then finishes the proxy update portion of the mobility update procedure by sending a Proxy Update Accept message to the new SGSN.

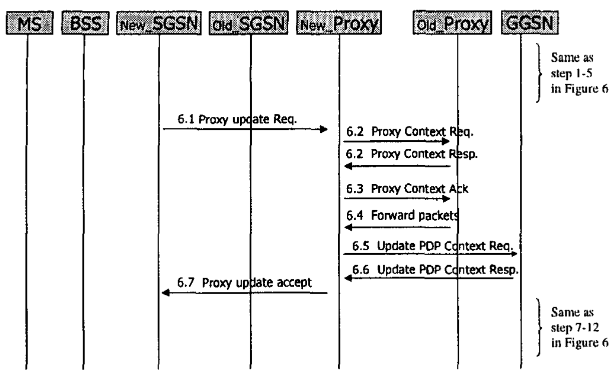

Fig. 7. GPRS mobility update procedure with proxy support.

The discussions above show that the GPRS standard can be easily expanded slightly to support proxies. If future GPRS is to extend IP support to base stations, similar procedure may be adopted to add proxies at base stations or between SGSN and base stations.

V. Summary

Performance enhancing proxy is a promising technique to improve user's experience with wireless data services by making information delivered to the user adaptive to devices, channel conditions, as well as user preferences. However, the performance of existing proxy services is limited by their service model in which proxies are located outside the wireless network and may even be very far away from mobile users. This paper studies an alternative approach which enables better, faster, and more secure proxy services by incorporating proxies into cellular networks. In particular, we examine issues that must be considered to determine how and where to place various proxy functions within cellular networks as well as their impacts on the system design. It turns out that the final decision involves balancing trade-offs between a number of factors including what information the proxy requires, the latency requirement for obtaining required information, the amount of extra traffic it generates, and mobility management, etc. We also illustrate how to add proxy support into GPRS by making only minor modifications to the PDP context creation and mobility update procedures. For future work, we plan to obtain quantitative performance results for various system designs.

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