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By Melvi Ulvan

Analysis of Session Establishment Signaling Delay in IP Multimedia Subsystem

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Abstract. This paper investigates and analyzes SIP delay in the session establishment signaling procedure in the IMS system. We investigate the delay for end-to-end link scenarios such as WiMAX-to-WiMAX, UMTS-to-UMTS, UMTS-to-WiMAX and vice versa. The analyses consider three types of delays: transmission delay, processing delay and queuing delay. The obtained results show that the main delay of session establishment signaling process is due to the processing delay. In addition, the lower channel rate in the UMTS network as well as IMS service rate has significant impact to the session establishment signaling delay.

Keywords: Wireless networks, IMS, SIP messages, Session delay.

1 Introduction

The IP Multimedia Subsystem (IMS) is the next generation IP based infrastructure enabling convergence of data, speech, video and mobile network technology. It is the foreseen solution that will provide new multimedia communication services by combining voice and data in an access independent IP based architecture. The IMS architecture is defined in 3GPP, 3GPP2 and IETF standards.

The Session Initiation Protocol (SIP, [1]) is used as a signaling protocol in the IMS environment. The SIP protocol provides functionalities such as terminal location, session establishment, session management and participant invocation, including creating, modifying, and terminating sessions with one or more participants. Sessions can contain any combination of services such as voice, data, audio, video, etc, and they can be modified at any time by adding new parties or changing the nature of session. In this paper, we shall consider the session establishment, particularly the signaling delay during the session establishment process.

The SIP-based IMS signaling delay for the IMS session establishment procedure is analyzed in [2]. The author analyzes the end-to-end delay if the source is a UMTS terminal and the destination is a WiMAX terminal and vice versa. The signaling delay is analyzed separately for transmission delay, processing delay and queuing delay. However, the paper just investigates the total delay,i.e. there is no information which delay part mostly contributes to the total delay. The optimization of SIP session setup delay for voice over IP (VoIP) service in 3G networks is studied in [3]. The authors

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evaluate the SIP session setup performances considering various underlying protocols (such as Transport Control Protocol, User Datagram Protocol, Radio Link Control) as function of frame error rate (FER). An adaptive retransmission timer is proposed to be implemented in order to optimize the delay. Analysis of SIP-based mobility management in 4G network is carried out in [4]. Though, the authors do not focus on the session establishment procedure, some delay issues are discussed, particularly the delay on radio link control (RLC) and non-RLC. Some of the considered values in [4] are used in our analyses.

In this paper, we review and analyze the delay of session establishment signaling process. Structure of session establishment signaling process that is based on the standard is presented. We analyze the delay, not only during the IMS processes where the S-CSCF, P-CSCF, I-CSCF and HSS take part, but we also take into account the transmission delay and delay when the SIP messages being queued in the network. The transmission delay is analyzed as end-to-end delay where the source terminal (ST) and the destination terminal (DT) are either UMTS or WiMAX terminals. In term of transmission delay, the RLC (Radio Link Control) delay at the UMTS network and the non RLC delay at the WiMAX network are considered. The queuing delay is analyzed for the M/M/1 model. We also examine which delay among the transmission, processing and queuing delays mostly contribute to the total delay.

The rest of the paper is organized as follows. In Section 2, we describe the IMS signaling messages for session establishment, as well as their features at different entities and different channel rates, and also the description of transmission, processing and queuing delays. The delay analyses and results are given in Section 3. Finally, Section 4 concludes our paper.

2 IMS Session Establishment Signaling

2.1 Session Establishment Procedure

The IMS architecture contains multiple SIP proxies called Call Session Control Functions (CSCFs) with following roles: i) P-CSCF (Proxy-CSCF) which is the first contact point in the IMS architecture and it interacts with GGSN (Gateway GPRS Support Node), ii) I-CSCF (Interrogating-CSCF) which acts as a SIP Registrar and is responsible for routing sessions to appropriate S-CSCF (Serving-CSCF), and finally iii) S-CSCF that performs session control and service trigger [4].

Figure 1 shows the session establishment flows in case a source terminal wants to establish a session with the destination terminal. The source terminal generates a SIP INVITE request and sends it to the P-CSCF. The P-CSCF processes the request; for example, it decompresses the request and verifies the user's identity before forwarding the request to the S-CSCF. The S-CSCF processes the request, executes service control which may include interactions with Application Servers (ASs) and eventually determines the entry point of home operator of user B based on user B's identity in the SIP INVITE request.

The I-CSCF receives the request and contacts the HSS (Home Subscriber Station) to find out the S-CSCF that is serving user B. The request is passed to the S-CSCF. The S-CSCF is in charge of processing the terminating session which may

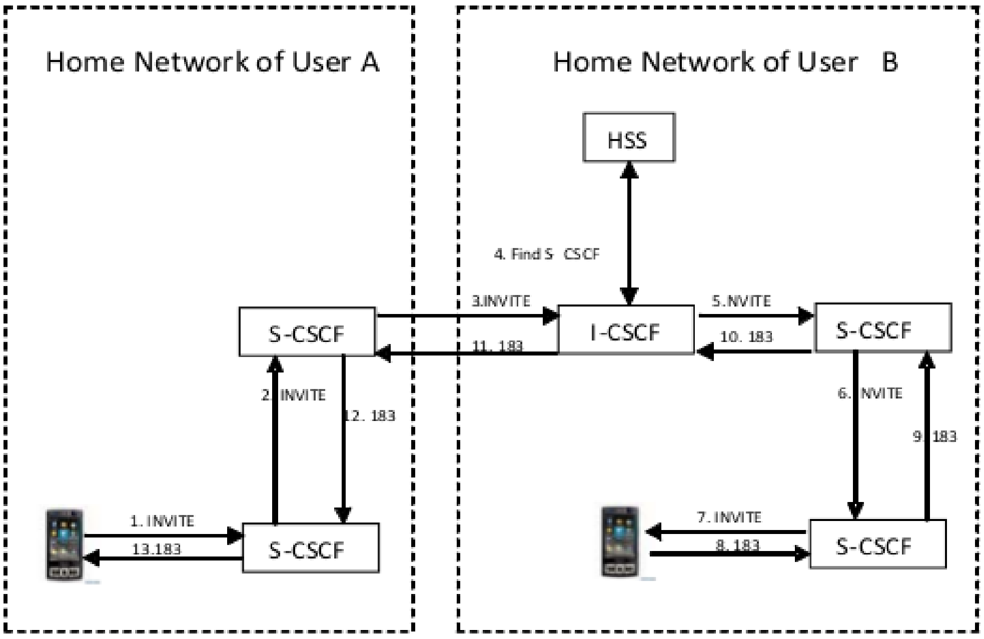


Fig. 1. Session establishment flows [5]

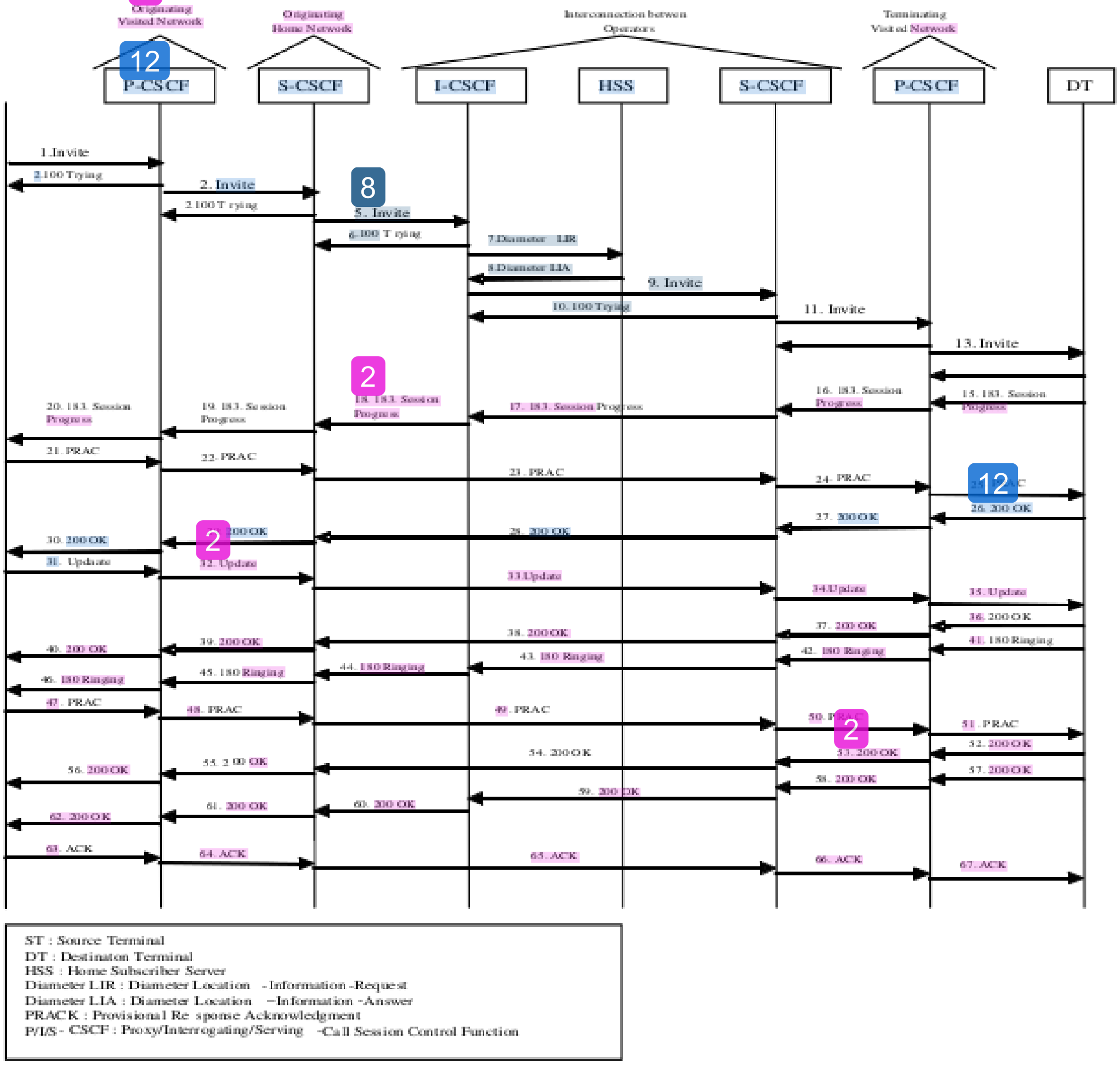
include interactions with ASs and eventually transmits the request to the P-CSCF. After further processing (e.g., compression and privacy checking), the P-CSCF transmits the SIP INVITE request to destination terminal (DT). The DT generates a response “183 Session Progress” that is sent back to the source terminal following the same route (i.e., DT → P-CSCF → S-CSCF → I-CSCF → S-CSCF → P-CSCF → ST). After a few more round trips, both, ST and DT, complete the session establishment phase and they are ready to start the application (e.g., voice call).

The whole call flow diagram of IMS session establishment procedure is shown in Figure 2. More details about the IMS session establishment procedure can be found for example in [5].

2.2 Session Establishment Messages

In general, there are three forms of IMS messaging; i) immediate messaging, ii) session-based messaging and iii) deferred delivery messaging [5]. Each form of IMS messaging has its own characteristics. The immediate messaging and session-based messaging operate in the IMS architecture directly. Moreover, the deferred delivery messaging form runs in the Packet-Switched (PS) domain that is an independent network infrastructure separated from the IMS. In this paper, we only consider the second case, session-based messaging, particularly the SIP messages that are involved in the session establishment procedure.

The SIP is an application protocol that is designed to establish communication *sessions* in request/response message model [1]. The SIP request message defines the operation requested by client whereas the SIP response message provides information from the server to the client indicating the status of that request. According to [1], there are six types of request messages: REGISTER, INVITE, ACK, CANCEL, BYE, and OPTION. As can be seen in figure 2, INVITE and ACK messages can only be involved in the session establishment procedure. Other request messages such as PRACK and UPDATE are defined in standard [6] and [7].



ST : Source Terminal
DT : Destinaton Terminal
HSS : Home Subscriber Server
Diameter LIR : Diameter Location - Information -Request
Diameter LIA : Diameter Location - Information -Answer
PRACK : Provisional Re sponse Acknowledgment
P/I/S - CSCF : Proxy/Interrogating/Serving -Call Session Control Function

Fig. 2. IMS session establishment procedure

The INVITE and UPDATE messages have similar functionalities. The first one, INVITE, indicates user or service to be invited to participate in a session. The structure of message includes a description of the session to which the destination terminal is being invited. The ACK message confirms that the destination terminal has received a final response to an INVITE request. ACK is only used with INVITE request. Whereas the UPDATE message allows a client to update parameters of session (such as the set media streams or used codec) but has no impact on the state of dialog. In that sense, it is like the re-INVITE message, but unlike re-INVITE, the transmission of UPDATE message can be preceded by the INVITE message. This makes it very useful when updating session parameters within the early stage of dialogs [8].

The PRACK request plays the same role as the ACK message, but it is for provisional responses. However, there is an important difference, the PRACK message is a normal SIP message such as BYE. .Its own reliability is ensured hop-by-hop through each stateful proxy. Also like BYE message, but unlike the ACK message, PRACK message has its own response [6].

To speed up the session establishment, the application protocol should compress the messages before transmission. The signaling compression (SigComp) is used as the compression standard. The 3GPP has mandated the support of SIP compression by both the user equipment (UE) and the P-CSCF [9]. However, the compression is currently mandatory and the 3GPP intends to eliminate the SIP compression in the future wireless networks (local, metropolitan). More details about SIP compression and SigCom can be found in [10][11] or [12].

In our analysis, we assume that the session establishment messages are compressed by SigComp. The size of session establishment messages, according to figure 2 and references [1] and [13], are given in table 1.

2.3 Analysis of Session Establishment Signaling Delays

The session establishment signaling delay is known as Session Initiation Delay (SID) which is defined as the period between the instant the originator of a session triggers the initiate session command and the instant the session initiator receives the message that the other party has been alerted. The ITU specification E.721 [14] defines the average delay for three connection types: local connection (3.0 sec), toll connection (5.0 sec) and international connection (8.0 sec). Another standard that is important to taken into consideration is ITU Rec. G.114 [15] that specified the network delay for voice application in packet networks.

In this paper, the delay is decomposed into three parts: transmission delay, processing delay and queuing delay. Thus, the end-to-end communication delay can be calculated as [2]:

$$D_{total} = D_{transmission} + D_{processing} + D_{queue} \quad (1)$$

2.3.1 Transmission Delay

In this paper, we consider four wireless end-to-end scenarios: UMTS-UMTS, WiMAX-WiMAX, UMTS-WiMAX and WiMAX-UMTS. The transmission delay is affected by the underlying protocols used by SIP (e.g. UDP, TCP, or RLC) that influence the session establishment time. Another affect may arise from the error recovery strategy (e.g. ARQ, FEC, HARQ, etc.).

The following channel data rates (B/W) are considered in our simulation scenarious: 19.2 kbps and 128 kbps for UMTS network, and 4 Mbps and 24 Mbps for WiMAX.

The number of frame in a packet (k) is required to be calculated for every specified channel rates. In UMTS, the RLC frame duration (τ) is assumed to be 20 ms. In case of WiMAX, the frame duration is set to be 2.5 ms. Additionally, the frame duration in WiMAX is independent on the channel bit rate. The number of bytes in a frame is equal to B/W x τ. The value of $\boldsymbol{k}$ for particular signaling messages (shown in table 1) can be calculated as:

$$k = number \;\; of \;\; byte \;\; / \;\; message \;\; size \quad (2)$$

Hence for instance, let's consider the INVITE message and the channel rate 19.2 kbps. Than, the number of byte per frame equals $19.2\text{x}10^{3}$ x $20\text{x}10^{-3}$ x 1/8= 48 bytes and value of $\boldsymbol{k}$, given by expression 2, equals 810/48 = 17.

By using the same method for other SIP messages and the given channel rates, we can determine the value of $\boldsymbol{k}$ corresponding to different types of messages involved in session establishment (Table 1).

Table 1. $\boldsymbol{k}$ value of SIP messages for specified channel rates

Session establishment message	Compressed size (byte)	Channel rate			
		19.2 kbps	**128 kbps**	**4 Mbps**	**24 Mbps**
INVITE	810	17	3	1	1
100 TRYING	260	6	1	1	1
183 SESSION PROGRESS	260	6	1	1	1
PRACK	260	6	1	1	1
200 OK	100	3	1	1	1
UPDATE	260	6	1	1	1
180 RINGING	260	6	1	1	1
ACK	60	2	1	1	1

2.3.1.1 *Transmission Delay in UMTS*

To analyze the delay to transmit SIP messages over the UMTS network, we exploit the delay model for frame and packet transmission over a wireless link which is proposed in [16][17]. The analysis of SIP transmission delay when transmitting a packet over the UMTS is given as:

$$D_{UMTS} = D + (k-1)\tau + \frac{k\left[P_f - (1-p)\right]}{P_f^2} \times \left| \sum_{j=1}^{n} \sum_{i=1}^{j} P(C_{ij}) \left[2jD + \left(\frac{j(j+1)}{2} + i \right) \tau \right] \right| \qquad (3)$$

The open-air operation of UMTS radio access network is vulnerable to noise influenced that generate packet loss. In equation 3 above, the effective packet loss is noted by P_f, and can be calculated as follow:

$$P_f = 1 - p + \sum_{j=1}^{n} \sum_{i=1}^{j} P(C_{ij}) = 1 - p\left[p(2-p)\right]^{n(n+1)/2} \qquad (4)$$

Where n is the maximum number of RLC retransmission trials and C_{ij} (representing the first frame received correctly at destination) is the i^{th} retransmission frame at the j^{th} retransmission trial.

2.3.1.2 *Transmission Delay in WiMAX*

In case of SIP re-transmission in WiMAX network, the SIP retransmission is considered to be provided by upper layer protocols (e.g., TCP) until the successful transmission is completed. The upper layer protocol packet loss rate ($\boldsymbol{q}$) in this case is given as $q = 1-(1-p)^2$, where $\boldsymbol{p}$ is the probability a frame and $\boldsymbol{k}$ is the number of frames per packet. Let's the number of retransmission denoted as $\boldsymbol{N_m}$, then the average delay of transmitting a packet over the WiMAX network ($\boldsymbol{D_{WiMAX}}$) is calculated as follow :[8][17]

$$D_{WiMAX} = (k-1)\tau + \frac{D}{(1-q^{N_m})(1-2q)} + \frac{1-q}{1-q^{N_m}} \times D\left[\frac{q^{N_m}}{1-q} - \frac{2^{N_m+1} \times q^{N_m}}{1-2q}\right] \quad (5)$$

The description of parameters involved in equation (3), (4) and (5) and their typical and assumed value are expressed at table 2.

Table 2. Parameters, description and values

Symbol	Parameter description	Value
ρ	Utilization	0.7 for HSS; 0.4 for other entities
T_f	Frame Duration	20 ms (UMTS); 2.5 ms (WiMAX)
μ	Processing rate for each SIP message	250 packet/s
p	Probability of a frame being in error	0.02 (constant)
D	Propagation delay	100 ms for UMTS; 0.27 (4 Mbps) 0.049 (24 Mbps)
k	Number of frames	5 (constant)
n	Maximum number of RLC transmission trials	3
L	IP address length in bits	32
S	Machine word size in bits	32
N_m	Number of User	5000

2.3.1.3 Total Transmission Delay

According to fig. 2, it can bee seen that the session establishment processes in the IMS involve 12 message exchanges between the source terminal and P-CSCF of the visited IMS network. In addition, there are another 12 message exchanges which are involved between P-CSCF of the terminating IMS network and destination terminal.

In our first scenario, the source and destination terminals are UMTS terminals. Thus, the IMS session establishment transmission delay is given as:

$$D_{trans-UMTS} = 24 messages \times D_{UMTS} \quad (6)$$

By using the same approach, we can determine the IMS session establishment transmission delay in case of WiMAX terminals as:

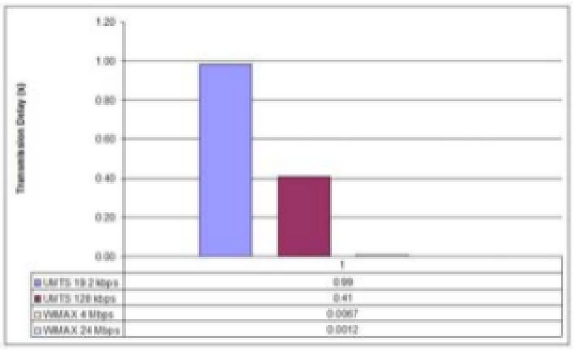
$$D_{trans-WiMAX} = 24 messages \times D_{WiMAX} \quad (7)$$

The results are depicted at figure 3. (a). It shows that the UMTS network has higher delay in transmission compare to WiMAX. The detail description can be found at section 3.

The third (resp. forth) scenario considers the source terminal to be UMTS terminal (resp. WiMAX) and the destination terminal represents WiMAX terminal (resp. UMTS). Thus, the session establishment transmission delay is given as:

$$D_{trans-UW/WU} = 12\, messages \times D_{UMTS} + 12 messages \times D_{WiMAX} \quad (8)$$

The obtained results are shown in figure 3 (b). It can be seen that the UMTS's channel rates affected the transmission delays. The lower channel rate contribute to the most significant delay.



(a) (b)

Fig. 3. (a) Session establishment transmission delay UMTS-UMTS and WiMAX-WiMAX ; (b) Session establishment transmission delay UMTS-WiMAX

2.4 Processing Delay

The processing delay is determined in all entities in the IMS signaling path, i.e. P-CSCF, I-CSCF, S-CSCF in both home and visited networks, plus the Home Subscriber Server (HSS) where the subscriber's profile is stored. The processing delay included the address lookup table delay. It is a delay when a query is sent to HSS for a particular IP address, then HSS has to lookup its table for the given IP address. The HSS table contains the list of N subscribers managed by the IMS network. Our work assumes $N = 5000$ subscribers.

The HSS lookup is an important part of the processing delay ($D_{proc-HSS}$), it can be approximated as [2][8]:

$$D_{proc-HSS} = D_{proc-ED} + 100\left(Log_{k'+1} N + \frac{L}{S}\right) \tag{9}$$

Where L is the length of IP address in bits (L=32 bits for IPv4 and L=128 bits for IPv6), S is the size of server's processor architecture (e.g., 32 or 64 bits), k' is a system-dependent constant, and $D_{proc-ED}$ represents the fixed processing delay due to the encapsulation and de-capsulation of packets. In our analyses, $D_{proc-ED}$ = 4 ms [2]. Since the encapsulation and decapsulation of packets are the only process that takes place in other entities, therefore we assumed the processing delays in rest of entities are equal to $D_{proc-ED}$.

The multiplication factor of 100 [3] in the equation 9 is used since the lookup time is increased by around 100 ns for each memory access. By using the given value of parameters, the multiplication part gave the result in nanoseconds. Since, the increase of multiplication part is too small, the value of $D_{proc-HSS}$ is assumed to equivalent to $D_{proc-ED}$.

The processing delay for the IMS session establishment process (D_{proc}) is given as:

$$D_{proc} = 7D_{proc-ST} + 24D_{proc-PCSCF} + 24D_{proc-SCSCF} + 6D_{proc-ICSCF} + D_{HSS} + 5D_{proc-DT} \tag{10}$$

where $D_{proc-ST}$, $D_{proc-PCSCF}$, $D_{proc-SCSCF}$, $D_{proc-ICSCF}$, $D_{proc-DT}$ denote the packet processing delay at source terminal, P-CSCF, S-CSCF, I-CSCF and destination terminal. The coefficients in equation (10) are determined based on the number and type of messages that each network entity has to process (see Figure 2). With respect to our assumptions, the value of D_{proc} is approximately 0.67 ms.

2.5 Queuing Delay

The queuing delay for the IMS session establishment process is determined in each network entity involved in the IMS signaling. The end-to-end packet delay from source to destination terminal depends on number of packets in each queue. In our analyses, we assume a queue model M/M/I and Poisson signaling arrival rate process. The queue model has a typical behavior which means if the input process to the first M/M/I queues is Poisson, then the input process to the next stage M/M/I queue is also Poisson process. The processes are independent one to other [16].

In addition, the queuing delay at the receiver buffer is only considered, The transmission buffer at a network node is supposed to be delay free. The packet delay at source terminal queue is approximated as:

$$D[\omega_{ST}] = \frac{\rho_{ST}}{\mu_{ST}(1-\rho_{ST})} \tag{11}$$

Where $\rho_{ST} = \frac{\lambda_{e-ST}}{\mu_{ST}}$ represents the utilization at the source terminal, μ_{ST} denotes the service rate at the source terminal, λ_{e-ST} represents the effective arrival rate at the ST:

$$\lambda_{e-ST} = \sum_{i \in N_{ST}} \lambda_i \tag{12}$$

Where N_{ST} denotes the number of active sessions including the considered IMS session. By determination of the utilization at a network node, the effective arrival rate λ_e at that node can be obtained. In the same way, the λ_e can be calculated at the other network entities. Thus, the queuing delay D_{queue} can be approximated as:

$$D_{queue} = 7D[\omega_{ST}] + 24D[\omega_{PCSCF}] + 24D[\omega_{SCSCF}] + 6D[\omega_{ICSCF}] + D[\omega_{HSS}] + 5D[\omega_{DT}] \tag{13}$$

where $D[\omega_{ST}]$, $D[\omega_{PCSCF}]$, $D[\omega_{SCSCF}]$, $D[\omega_{ICSCF}]$, $D[\omega_{HSS}]$ and $D[\omega_{DT}]$ denotes the expected value of a unit packet queuing delay at Source Terminal, P-CSCF, S-CSCF, I-CSCF, HSS and Destination Terminal. Based on equation (13) the queuing delay in our analyses equals to 0.255 ms.

2.6 Total Delay for Session Establishment Procedure

Based on the previously deduced equations, the total, end-to-end, delay for the IMS session establishment procedure can be now calculated. In case, the source and destination terminal are UMTS terminals, resp. WiMAX ones, the total delay is given by equation (14), resp. (15):

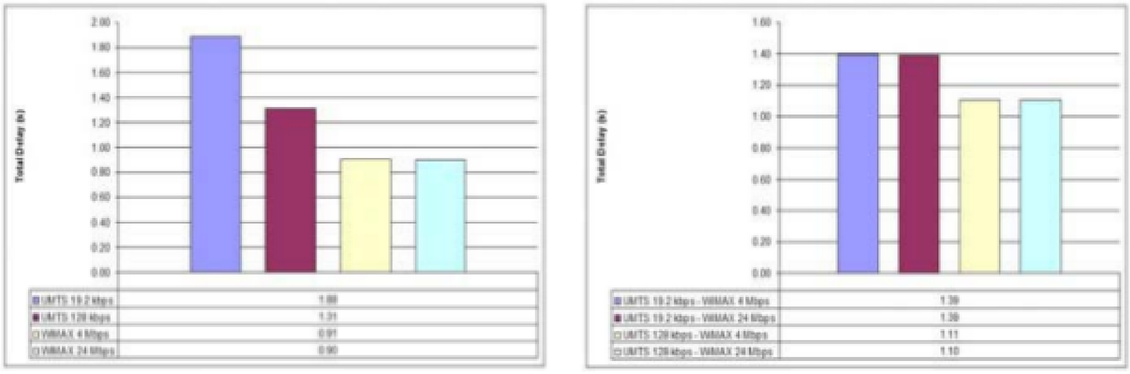
$$D_{total-UMTS} = D_{trans-UMTS} + D_{proc} + D_{queue} \tag{14}$$

$$D_{total-WiMAX} = D_{trans-WiMAX} + D_{proc} + D_{queue} \tag{15}$$

If the source terminal is a UMTS terminal and the destination terminal is a WiMAX terminal, and vice versa, the total end-to-end delay is given by:

$$D_{total-UMTS/WiMAX} = D_{trans-UMTS/WiMAX} + D_{proc} + D_{queue} \tag{16}$$

The results obtained from equations (14) and (15) are shown in Figure 4.(a). In addition, the results of equation (16) can be seen in Figure 4.(b). Based on both figures, it can be observed that UMTS and WiMAX networks have different profile to deal with IMS session establishment delay. The higher delay may be a factor of transmission delay in UMTS network as seen in Figure 6, but perhaps it is not the most delay contributor.



(a) (b)

Fig. 4. (a) The total delay of IMS session establishment for UMTS-UMTS and WiMAX-WiMAX, (b) The total delay of IMS session establishment for UMTS-WiMAX

3 Numerical Results

Based on results obtained in the previous section, this section presents description of the delay analysis within the IMS session establishment procedure. Chosen values of parameters for the analysis are listed in Table 2.

Figure 3. (a) shows the transmission delay when the source and destination terminals are UMTS terminals, resp. WiMAX terminals. It can be observed that the session establishment delay is significantly affected by the channel data rate, since the delay considerably decreases as the channel rate increases. The WiMAX network scenario with higher channel rates outperforms the UMTS network scenario. Additionally, the session establishment delay is negligibly affected by modifying the WiMAX channel rates. The value of ***k* remains** the same for higher channel rate.

The network links have a slight impact on both delays since the processing and queuing delays are influenced by the processes that take place in each network entities such as P-CSCF, S-CSCF, I-CSCF and HSS, source and destination terminals. The processing and queuing delays are more affected by IMS service/processing rate, signalling arrival rate and by number of subscribers. Figure 5 shows the impact of different service rates on the session establishment delay. The delay decreases as the service rate increases, different channel rates has slight impact on the delay.

Typical values of transmission delay depend on the end-to-end delay scenario. If the source and destination terminals are WiMAX terminals, the typical transmission delay is very small and can be neglected (Figure 3. (a)). On the other hand, in case of UMTS, the typical transmission delay is approximately 1ms (at 19.2 kbps) and 0.4 ms (at 128 kbps). In case of UMTS-WiMAX scenario, as seen in Figure 3.(b), the typical transmission delay value is about 0.5 ms (UMTS-19.2 kbps) or 0.2 ms (UMTS-128 kbps).

The typical processing and queuing delay values are approximately 0.67 ms and 0.225 ms, respectively. Therefore, based on Figure 4 (a) and (b), the total value of IMS session establishment delay in all end-to-end scenarios can be observed as follow:

- UMTS - UMTS: 1.31 ms (at 128 kbps) and 1.88 ms (at 19.2 kbps).
- WiMAX - WiMAX : around 0.9 ms (for the given channel rates).
- UMTS to WiMAX: approximately 1.4 ms and 1.1 ms at 19.2 kbps and 128 kbps.

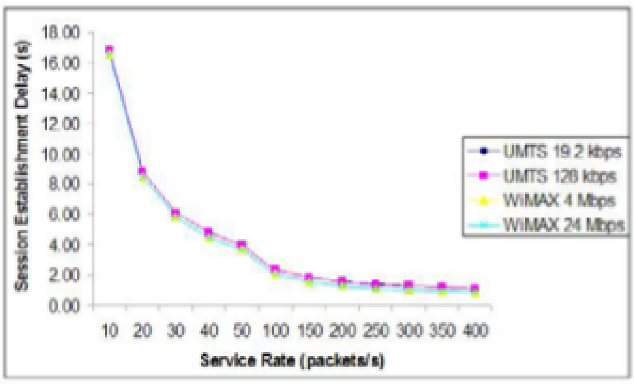


Fig. 5. Effect of changing service rate (μ) on IMS session establishment delay

4 Conclusions

This paper analyses signalling delay of session establishment procedure in the IMS environment. There are considered 4 scenarios UMTS to UMTS, WiMAX to WiMAX, UMTS to WiMAX (and vice versa) and different types of delays are taken into account. The results indicate that the processing delay contributes the major delay of the session establishment procedure. In addition, lower channel rates of UMTS network have a major impact on the delay. The session establishment delay decreases as the service rate increases. Obtained results are in the range that is specified by standards.

Since the IMS should support various technology platforms, therefore the optimization of session establishment procedure is required to be examined to allow the lower channel rates work within the grade of service. In addition, the investigation of delay in IMS applications, e.g. VoIP application and messaging, has benefit to increase the system performance.

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