LCSCW2: An Architecture for IP Multimedia Subsystems [*]

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ABSTRACT

The future fourth generation wireless heterogeneous networks aim to integrate various wireless access technologies and to support the IMS (IP multimedia subsystem) sessions. In this paper, we propose the Loosely Coupled Satellite-Cellular-WiMax-WLAN (LCSCW2) interworking architecture. The LCSCW2 architecture uses the loosely coupling approach and integrates the satellite networks, 3G wireless networks, WiMax, and WLANs. It can support IMS sessions and provide global coverage. The LCSCW2 architecture facilitates independent deployment and traffic engineering of various access networks. We also propose an analytical model to determine the associate cost for the signaling and data traffic for inter-system communication in the LCSCW2 architecture. The cost analysis includes the transmission, processing, and queueing costs at various entities. Numerical results are presented for different arrival rates and session lengths.

General Terms

IP multimedia subsystem, network architecture, heterogeneous wireless networks

1. INTRODUCTION

The IP multimedia subsystem (IMS) is standardized by the 3rd generation partnership project (3GPP) and 3GPP2 as a new core network domain [1]. The IMS enables the provision of IP-based multimedia applications to mobile users, guarantees quality of service (QoS) across different access network technologies, and permits service providers to charge according to different policies. In addition, the IMS enables third-party vendors to develop new applications for operators and users. A growing number of telecommunication vendors are beginning to release devices and services based on the IMS.

The success of the future fourth generation (4G) wireless heterogeneous networks depends on the successful integration of the currently available wireless access technologies. Various interworking architectures have been proposed in the literature. An integrated universal mobile telecommunications system (UMTS) IMS architecture is presented in [2]. Different scenarios in the 3GPP specifications for WLAN-3G integration are discussed in [3]. The loose coupling and tight coupling interworking architectures are presented in [4]. An architecture which integrates CDMA2000 and 802.11 WLAN is proposed in [5]. The integration of satellite with terrestrial systems is discussed in [6]. In [7], an architecture for UMTS-WiMax (Worldwide Interoperability for Microwave Access) interworking is proposed and the signaling flows for handover from WiMax to UMTS access network are given. In [8], an architecture is proposed for the integration of WiMax and UMTS based on loosely-coupled approach. In [9], an S-UMTS architecture is proposed and the signaling flows for registration, call handling and handover are given. In [10], an architecture that integrates satellite, WLAN and 3G networks is proposed which requires a third party to handle service level agreements (SLAs). In [11, 12], architectures based on tight coupling and loose coupling paradigm are proposed and their corresponding cost analysis is performed.

In this paper, we propose a novel 4G interworking architecture, called Loosely Coupled Satellite-Cellular-WiMax-WLAN (LCSCW2). The LCSCW2 architecture integrates various access networks including the satellite networks, 3G wireless networks, WiMax, and WLANs. Our proposed architecture is based on the loosely coupling approach. It can support IMS sessions and provide global coverage. We also perform a cost analysis for the signaling and data traffic for inter-system communication in the LCSCW2 architecture. The cost analysis includes the transmission, processing, and queueing costs at various entities. The cost analysis will be of significance for the service providers to analyze the individual network elements as well as the architecture comprehensively.

The rest of the paper is organized as follows: In Section 2, we present our proposed LCSCW2 interworking architecture. In Section 3, we describe an analytical model to determine the cost for IMS signaling and data traffic. Numerical results are presented in Section 4. Conclusions are given in Section 5.

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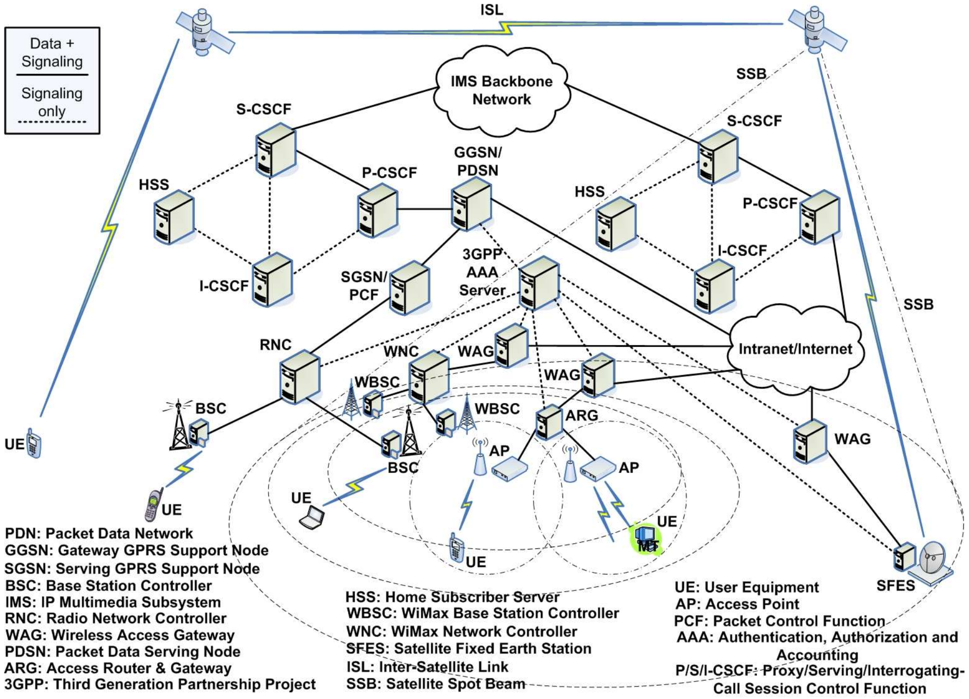

Figure 1: The LCSCW2 Interworking Architecture.

2. THE LCSCW2 ARCHITECTURE

Our proposed LCSCW2 interworking architecture is depicted in Figure 1. This novel interworking architecture integrates satellite networks, 3G wireless cellular networks, WiMax, and WLANs based on the loosely coupled approach. The areas covered by the satellite spot beams (SSBs), 3G base stations, WiMax base stations, and WLAN access points (APs) are shown by dotted lines in Figure 1. Our proposed architecture is compatible with the IMS. Different access networks (ANs) (e.g., 3G networks, satellite networks, WiMax, and WLANs) can be owned by different service providers (or the same operator). The wireless access gateways (WAGs) of WLAN, WiMax, satellite and 3G networks are connected to different proxy-call session control function (P-CSCF) servers in IMS via the Internet. In general, each AN has its own separate WAG. In addition, there are separate serving-call session control function (S-CSCF) and interrogating-call session control function (I-CSCF) servers for the two networks. For the establishment of an IMS session between two access networks, the two service providers should have a SLA with each other. IMS networks which are owned by different operators are connected together through an IMS backbone network. The WAG and packet data serving node (PDSN) are connected to the same P-CSCF server if WLAN, WiMax, satellite and 3G network are owned by the same operator.

The mechanisms involved in the interworking architecture along with the functionalities of various entities are explained below with reference to the 3GPP specification [15]. Access to a locally connected IP network from a WLAN directly is called "WLAN direct IP access", which is provided by the loosely coupled architecture. The WAG is a gateway via which the data to/from the satellite AN, WiMax AN, or WLAN AN can be routed to/from an external IP network. In the LCSCW2 architecture, the satellite AN comprises of satellites and satellite fixed earth station (SFES). Satellites convey data and signaling messages between user equipment (UE) and SFES. The SFES performs power control, link control, radio bearer control and paging functions. The SFES is connected to WAG for accessing 3GPP packet switched (PS) and IMS services. The WiMax AN consists of WiMax base stations, which are controlled by the WiMax base station controller (WBSC). Several WBSCs are controlled by one WiMax network controller (WNC). The WNC is connected to WAG to provide WiMax users with 3GPP PS and IMS services. The LCSCW2 interworking architecture integrates satellite networks, 3G wireless networks, WiMax, and WLANs based on the loose coupling approach since these ANs connect to the Internet or Intranet via WAG. Then, through the Internet or Intranet, the UE can access CSCF servers of the IMS network.

In the LCSCW2 architecture, the satellite network, WiMax and WLAN do not have any direct link to 3G network elements such as serving GPRS support nodes (SGSNs) or gateway GPRS support nodes (GGSNs). The LCSCW2 architecture has distinct signaling and data paths for different ANs. The inter-operability with 3G requires the support of mobile-IP functionalities and Session Initiation Protocol (SIP) to handle mobility across networks, and authentication, authorization, and accounting (AAA) services in the WAG of the AN. This support is necessary to interwork with the 3G's home network AAA servers. The authentication in the ANs is provided through the 3GPP system [15]. The main advantage of the LCSCW2 architecture is that it allows independent deployment and traffic engineering of

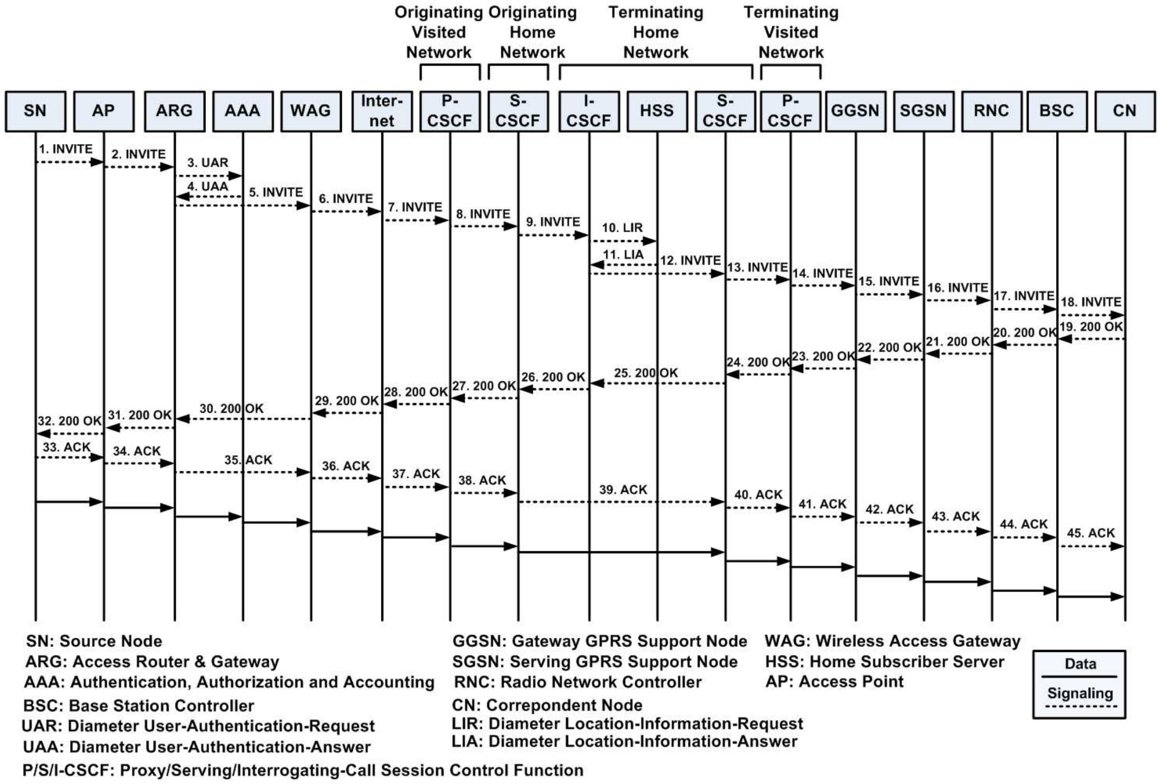

Figure 2: Signaling and data communication paths between WLAN and 3G for IMS session in the LCSCW2 architecture [13], [14].

satellite networks, WiMax, WLANs, and 3G networks. In addition, this architecture utilizes standard IETF (Internet Engineering Task Force) based protocols for AAA and mobility in the WiMax, WLANs, and satellite networks.

3. AN ANALYTICAL MODEL FOR COST ANALYSIS

We use the inter-system communication cost analysis to evaluate the performance of our proposed LCSCW2 interworking architecture. The total inter-system communication cost C_s is given by:

$$C_s = C_t + C_p + C_q \tag{1}$$

where C_t, C_p, and C_q denote the transmission cost, processing cost, and queueing cost, respectively. The transmission cost C_t is the cost incurred due to the transmission of signaling and/or data. It depends on the packet arrival rate, the transmission rate of the link, and the distance between the neighboring network entities. The processing cost C_p is the cost associated with the encapsulation, decapsulation and routing of packets. The queueing cost C_q is the cost incurred due to the queuing of packets in each network entity. Our analysis is applicable to both IPv4 and IPv6 packet types. Also, our analysis is valid for both UMTS and CDMA2000 3G networks.

In the LCSCW2 architecture, communication paths are different when the source node (SN) resides in either WiMax, WLAN or satellite network. In the following analysis, we assume that SN is communicating via a WLAN and the correspondent node (CN) is using a 3G wireless cellular network. However, the analysis can easily be extended for the case when the SN is communicating via WiMax or satellite network.

3.1 Available Paths for Communications

Figure 2 shows the communication path between WLAN and 3G for an IMS session. The solid arrows show the data traffic communication path whereas the dashed arrows indicate the signaling traffic communication path from the SN to the CN. We consider the IMS session establishment signaling [13], [14] where the SN sends a SIP INVITE message to the CN. The SIP 200 OK message is sent from the CN to the SN. The SIP ACK message from the SN to the CN indicates the completion of session establishment procedure. The signaling incorporates the authentication from the 3GPP AAA server and the query of the user's profile from the HSS database based on Diameter protocol messages [16]. Note that for simplicity, we do not consider the provisional responses such as "100 Trying" in the signaling path.

3.2 Transmission Cost

Let λ denote the IMS session arrival rate (requests per second) and $\overline{\ell}$ denote the number of packets per request both for signaling and data from a SN. For transmission and processing cost calculation of IMS signaling traffic, $\overline{\ell}$ is equal to 1 because we assume that one signaling packet can carry one particular signaling message such as 200 OK from one node to its adjacent node. We take into account the traffic coming from other users in the same AN as well as from other ANs by considering background utilization at network entities. The transmission cost between WLAN and 3G wireless cellular networks for IMS signaling traffic C_t^{sig} is:

$$\begin{aligned} C_t^{sig} &= \lambda\bar{\ell}(2\varphi + \psi(3d_{ap-arg} + 2d_{arg-aaa} + 3d_{arg-wag} \\ &\quad + 3d_{wag-inet} + 3d_{inet-pcscf} + 6d_{pcscf-scscf} \\ &\quad + 4d_{scscf-icscf} + d_{scscf-scscf} + 2d_{icscf-hss} \\ &\quad + 3d_{pcscf-ggsn} + 3d_{sgsn-ggsn} + 3d_{sgsn-rnc} \\ &\quad + d_{rnc-bsc})) \end{aligned} \tag{2}$$

where φ and ψ are the unit packet transmission costs in wireless and wired link respectively; d_{ap-arg}, $d_{arg-aaa}$, $d_{arg-wag}$, $d_{wag-inet}$, $d_{inet-pcscf}$, $d_{pcscf-scscf}$, $d_{scscf-icscf}$, $d_{scscf-scscf}$, $d_{icscf-hss}$, $d_{pcscf-ggsn}$, $d_{sgsn-ggsn}$, $d_{sgsn-rnc}$, and $d_{rnc-bsc}$ denote the distance between AP and ARG, ARG and AAA, ARG and WAG, WAG and Internet, Internet and P-CSCF, P-CSCF and S-CSCF, S-CSCF and I-CSCF, S-CSCF server of the SN IMS network and the S-CSCF server of the CN IMS network, I-CSCF and HSS, P-CSCF and GGSN, SGSN and GGSN, SGSN and RNC, and RNC and BSC, respectively. The distance is defined as the number of hops that a packet has traveled.

The transmission cost between WLAN and 3G wireless cellular networks for IMS data traffic C_t^{data} is:

$$\begin{aligned} C_t^{data} &= \lambda\bar{\ell}(2\varphi + \psi(d_{ap-arg} + d_{arg-wag} + d_{wag-inet} \\ &\quad + d_{inet-pcscf} + 2d_{pcscf-scscf} + d_{scscf-scscf} \\ &\quad + d_{pcscf-ggsn} + d_{ggsn-sgsn} + d_{sgsn-rnc} \\ &\quad + d_{rnc-bsc})) \end{aligned} \tag{3}$$

By following the same methodology, we can calculate the transmission cost for communication paths between WiMax and 3G, as well as satellite and 3G for IMS traffic.

3.3 Processing Cost

For processing cost calculation, we first assume that N_{bsc} BSCs are connected to each RNC, N_{rnc} RNCs are connected to each SGSN, N_{sgsn} SGSNs are connected to each GGSN, N_{ggsn} GGSNs and N_{pcscf} P-CSCFs are connected to the Internet. In addition, let N_{mn1}, N_{mn2}, N_{mn3}, and N_{mn4} denote the number of users in the coverage area of 3G wireless cellular network, WLAN, WiMax, and SSB of the satellite network, respectively. The total number of users N in the network can be given as:

$$N = N_{mn1} + N_{mn2} + N_{mn3} + N_{mn4} \tag{4}$$

The processing cost between WLAN and 3G wireless cellular network for IMS signaling traffic C_p^{sig} is:

$$\begin{aligned} C_p^{sig} &= 3C_{p-ap} + 4C_{p-arg} + C_{p-aaa} + 3C_{p-wag} \\ &\quad + 3C_{p-inet} + 6C_{p-pcscf} + 6C_{p-scscf} \\ &\quad + 3C_{p-icscf} + C_{p-hss} + 3C_{p-ggsn} \\ &\quad + 3C_{p-sgsn} + 3C_{p-rnc} + 3C_{p-bsc} \end{aligned} \tag{5}$$

where C_{p-ap} represents the processing cost at AP and is given as:

$$C_{p-ap} = \lambda\bar{\ell}\gamma_{ap} \tag{6}$$

where γ_{ap} denotes the unit packet processing cost at AP. The unit packet processing cost includes the cost for encapsulation and decapsulation of packets. Similarly, the terms C_{p-arg}, C_{p-wag}, $C_{p-pcscf}$, $C_{p-scscf}$, and $C_{p-icscf}$ represent the processing costs at ARG, WAG, P-CSCF, S-CSCF and I-CSCF, respectively. Their expressions are similar to that of C_{p-ap} with the only difference that they have their own respective unit packet processing costs. C_{p-aaa} represents the processing cost at the AAA server and is given by:

$$C_{p-aaa} = \lambda\bar{\ell}\left(\gamma_{aaa} + \omega_1\left(\log_{k+1} N + \frac{L}{S}\right)\right) \tag{7}$$

where γ_{aaa} denotes the unit packet processing cost at AAA server. We assume that IP addresses are searched in the lookup table using the multiway and multicolumn search [17]. We also assume that the number of entries in the lookup tables for AAA server and HSS are equal to the total number of users N in the network because 3GPP AAA server based authentication and subscription database HSS are used [15]. In addition, L is the IP address length in bits (e.g. L is 32 for IPv4 and 128 for IPv6), S is the machine word size in bits, and k is a system-dependent constant. In our analysis, ω_i where $i \in \{1, 2, 3, 4\}$ denotes the weighting factors. C_{p-hss} represents the processing cost at HSS and its expression is similar to that of C_{p-aaa} with the only difference that it has its own specific unit packet processing cost. C_{p-ggsn}, C_{p-sgsn}, C_{p-rnc}, and C_{p-bsc} represents the processing costs at GGSN, SGSN, RNC, and BSC respectively with similar expressions as that of C_{p-aaa} with the difference that they have their own respective unit packet processing costs. Also, the logarithm is taken for N_{sgsn} in case of C_{p-ggsn}, N_{rnc} in case of C_{p-sgsn}, N_{bsc} in case of C_{p-rnc}, and N_{mn1} in case of C_{p-bsc} instead of N in the expression of C_{p-aaa}. C_{p-inet} represents the processing cost at the Internet and is given as:

$$C_{p-inet} = \lambda\bar{\ell}\left(\gamma_{inet} + \omega_2\left(\log_{k+1}(N_{gp}) + \frac{L}{S}\right)\right) \tag{8}$$

where γ_{inet} denotes the unit packet processing cost at the Internet, $N_{gp} = N_{ggsn} + N_{pcscf}$, and $\bar{\ell}$ is equal to 1 for IMS signaling processing cost calculation.

The processing cost between WLAN and 3G wireless cellular network for IMS data traffic C_p^{data} is:

$$\begin{aligned} C_p^{data} &= C_{p-ap} + C_{p-arg} + C_{p-wag} + C_{p-inet} \\ &\quad + 2C_{p-pcscf} + 2C_{p-scscf} + C_{p-ggsn} \\ &\quad + C_{p-sgsn} + C_{p-rnc} + C_{p-bsc} \end{aligned} \tag{9}$$

Following the same approach, we can calculate the processing cost for communication paths between WiMax and 3G, as well as satellite and 3G for IMS traffic.

3.4 Queueing Cost

For the queueing cost calculation, we first model the communication path between SN and CN as a network of M/M/1 queues [18]. The queueing cost is proportional to the total number of packets in the queueing network. The queueing cost between WLAN and 3G wireless cellular network for

IMS signaling traffic C_q^{sig} is:

$$\begin{aligned} C_q^{sig} \;=\; & \omega_3(3E[n_{ap}] + 4E[n_{arg}] + E[n_{aaa}] + 3E[n_{wag}] \\ & + 3E[n_{inet}] + 6E[n_{pcscf}] + 6E[n_{scscf}] \\ & + 3E[n_{icscf}] + E[n_{hss}] + 3E[n_{ggsn}] \\ & + 3E[n_{sgsn}] + 3E[n_{rnc}] + 3E[n_{bsc}]) \qquad (10) \end{aligned}$$

where $E[n_{ap}]$, $E[n_{arg}]$, $E[n_{aaa}]$, $E[n_{wag}]$, $E[n_{inet}]$, $E[n_{pcscf}]$, $E[n_{scscf}]$ $E[n_{icscf}]$, $E[n_{hss}]$, $E[n_{ggsn}]$, $E[n_{sgsn}]$, $E[n_{rnc}]$, $E[n_{bsc}]$ denote the expected number of packets in the queue of AP, ARG, AAA, WAG, Internet, P-CSCF, S-CSCF, I-CSCF, HSS, GGSN, SGSN, RNC, and BSC, respectively. The value of $E[n_{ap}]$ is equal to:

$$E[n_{ap}] = \frac{\rho_{ap}}{1 - \rho_{ap}} \qquad (11)$$

where $\rho_{ap} = \lambda_{e-ap}/\mu_{ap}$ represents the utilization at AP queue, μ_{ap} denotes the service rate at AP queue and λ_{e-ap} represents the *effective arrival rate* (in packets per second) at AP queue. That is, $\lambda_{e-ap} = \sum_{i \in N_{ap}} \lambda_i$, where N_{ap} denotes the number of active users in the AP coverage area that are engaged in communication with the AP, and hence $N_{ap} \subseteq N_{mn2}$. The effective arrival rate λ_e at a network node can be determined from the utilization at that node. Similarly, the λ_e at queues of other network nodes can be calculated and expressions can be determined for the expected number of packets at other network entities.

The queueing cost between WLAN and 3G wireless cellular network for IMS data traffic C_q^{data} is:

$$\begin{aligned} C_q^{data} \;=\; & \omega_4(E[n_{ap}] + E[n_{arg}] + E[n_{wag}] + E[n_{inet}] \\ & + 2E[n_{pcscf}] + 2E[n_{scscf}] + E[n_{ggsn}] \\ & + E[n_{sgsn}] + E[n_{rnc}] + E[n_{bsc}]) \qquad (12) \end{aligned}$$

Following the same approach, we can calculate the queueing cost for communication paths between WiMax and 3G, as well as satellite and 3G for IMS traffic.

4. NUMERICAL RESULTS

In this section, we present the numerical results for the cost analysis of our proposed LCSCW2 interworking architecture. The total system signaling and data costs for IMS traffic are determined for the case when the SN is using the WLAN and the CN is in 3G wireless cellular network.

We consider a network containing two 3G BSCs, three WiMax BSCs, 12 WLANs, and one SSB. The cell radius for 3G BSC, WiMax BSC, and WLAN is taken to be 1000 m, 700 m, and 50 m, respectively. Their user densities are taken to be 0.001, 0.001, and 0.008 per square meter, respectively [11], [12], [10]. The SSB is assumed to cover an area of 20 square kilometer and user density in its coverage area is taken to be 0.0005 per square meter [19]. The number of users resulting from the selection of these cell radii and user densities in different ANs are: $N_{mn1} = 5000$, $N_{mn2} = 600$, $N_{mn3} = 3000$, and $N_{mn4} = 10000$. In our network setting, two GGSNs and two P-CSCF servers are connected to the Internet; each GGSN supports three SGSNs; each SGSN supports four RNCS, and each RNC controls five BSCs. The IP address length L and processor machine word size S are taken to be 32 bits. The system dependent constant value k is equal to 5 [17]. The wired hop distances, $d_{pcscf-ggsn}$ and $d_{sgsn-rnc}$, which involve the core 3G network entities are equal to 4, and rest of the distances are equal to 2 [11], [12], [20]. The trunked Pareto distribution is assumed for packet length with average packet length equal to 480 bytes. The inter-arrival time for packets is exponentially distributed [21].

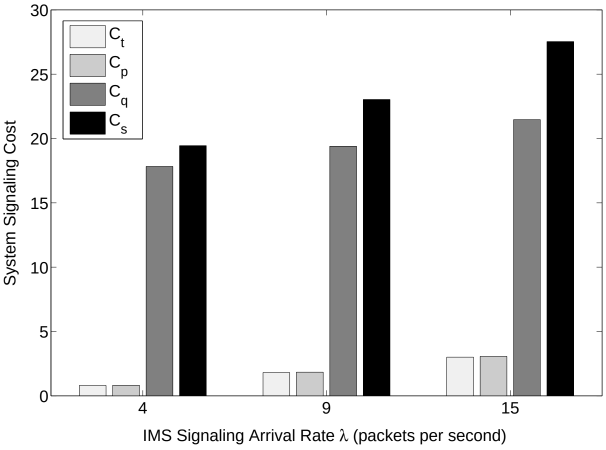

Figure 3: The breakup of system signaling cost into transmission, processing and queueing cost for different values of IMS signaling arrival rate λ.

The weighting factors, ω_1 and ω_2, corresponding to the table lookup processing cost are taken equal to 1×10^{-6} as lookup delay is increased by 100 ns for each memory access [17]. The weighting factors, ω_3 and ω_4, corresponding to queueing cost are equal to each other and are chosen such that sum of all the weighting factors is equal to 1 (i.e. $\sum_i \omega_i = 1$). We consider wireless link channels to be 9.6 kbps, 19.2 kbps or 19.2 kbps and the wired links to be 1 Gbps. The unit transmission costs for the wired link ψ and the wireless link φ are equal to 3.84×10^{-6} and 0.1, respectively [22], [23] so that the unit transmission costs can be interpreted as typical wireless and wired link delays in seconds. The service rate μ at all the network entities is taken equal to 250 packets/sec. The unit packet processing cost for all the network entities is taken equal to 4×10^{-3} except the core 3G network entities i.e. SGSN and GGSN and the Internet for which the unit packet processing cost is taken twice as compared to other network entities in accordance with [11], [12].

For IMS data traffic, we consider audio and video sessions using different codecs which give different packet generation rates. For instance, GSM voice encoder at 13 kbps, G.726 voice encoder at 32 kbps, H.264/AVC at 56 kbps, H.264/AVC at 80 kbps, H.264/AVC at 90 kbps give packet generation rates of 4, 9, 15, and 21 packets/sec, respectively [24], [8]. The background utilization due to traffic from other sources is taken to be 0.7 for HSS and AAA server because they have to handle traffic for inter-system communications from different ANs, 0.5 for the core 3G entities i.e. SGSN and GGSN, and 0.4 for the rest of the entities. The assumption of these values of background utilizations allows us to determine λ_e at each of the network nodes.

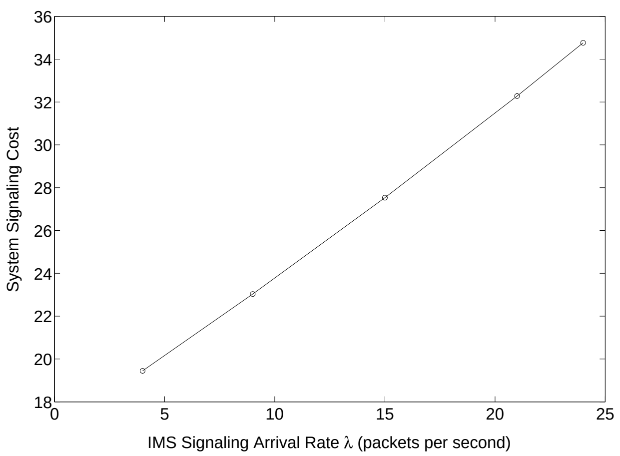

Figure 4: Effect of varying the IMS signaling arrival rate λ on the total system signaling cost between WLAN and 3G in the LCSCW2 architecture.

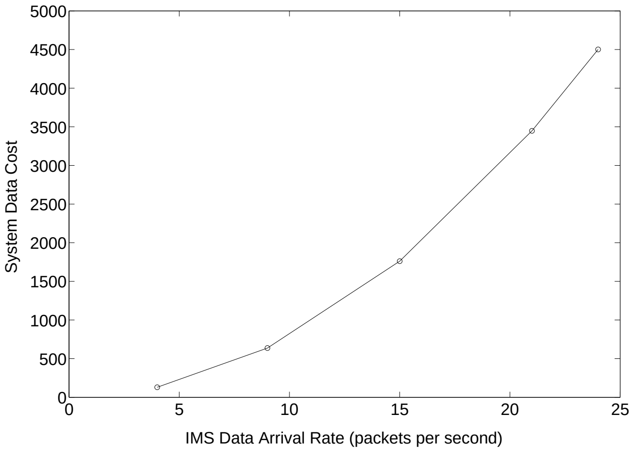

Figure 5: Effect of varying the IMS data arrival rate λ on the total system data cost between WLAN and 3G in the LCSCW2 architecture.

Figure 3 shows the transmission, processing and queueing costs, as well as the total system signaling cost, for IMS signaling traffic. Results show that that the ratio $C_t : C_p$ is 1 : 1.02 for signaling. With our selection of parameters, queueing cost is higher than the transmission and processing costs for signaling and lower than the transmission and processing costs for data.

Figure 4 shows the effect of varying IMS signaling arrival rate λ on total system signaling cost. It can be observed that the system signaling cost increases almost linearly with the increasing value of λ.

Figure 5 shows the effect of varying IMS data traffic arrival rate λ resulting from using different audio and video encoders on total system data cost. It can be observed that the system data cost increases non-linearly with the increasing value of λ. The linear increase of system signaling cost and non-linear increase of system data cost with λ is dependent on the ratios of transmission, processing and queueing costs in the total system cost.

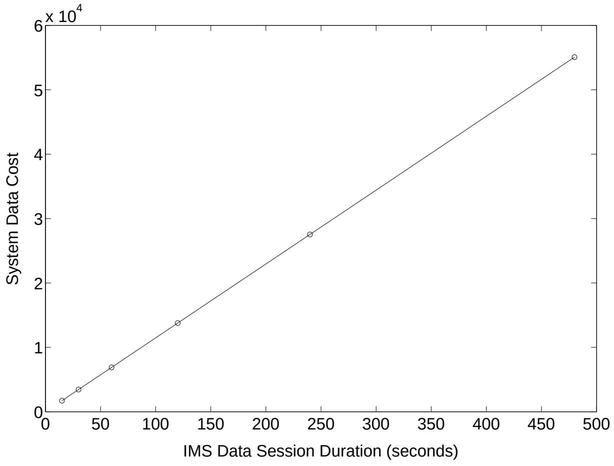

Figure 6: Effect of varying the average IMS session duration $\bar{\ell}$ on the total system data cost between WLAN and 3G in the LCSCW2 architecture.

Figure 6 shows the effect of varying IMS session duration on total system data cost. The arrival rate λ is assumed to be to 21 packets/sec. The IMS data session is run for 30, 60, 120, 240, and 480 seconds with the corresponding values of $\bar{\ell}$ as 315, 630, 1260, 2520, 5040, and 10080, respectively. Results show that the system data cost increases almost linearly with increasing session length.

5. CONCLUSIONS

In this paper, we proposed the LCSCW2 interworking architecture for 4G heterogeneous wireless networks. The LCSCW2 architecture integrates the satellite networks, 3G wireless networks, WiMax, and WLANs. The LCSCW2 architecture supports IMS sessions, provides global coverage, and facilitates independent deployment of various access networks. We also proposed a cost model to determine the associate cost for the IMS signaling and data traffic in the LCSCW2 architecture. We presented the numerical results for the system cost, as well as the transmission, processing, and queueing costs under different arrival rates and session lengths.

Acknowledgment

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