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# End-to-End Delay, Throughput, and Performance Analysis of Satellite-UMTS Telecommunication Networks

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***Abstract*—In recent years, achieving world-wide multimedia wireless services has received wide-spread attention and is the most desired objective of service providers of telecommunication networks. Thus, a significant amount of research efforts is devoted to broaden the wireless services over the globe. In this context, satellite component plays a pivotal role in extending and enhancing the existing Universal Mobile Telecommunication System (UMTS). In this paper, integration of satellite communication systems with UMTS is addressed. Several integration scenarios are considered and their simulation results using Network Simulator (NS) are given. In particular, performance of integration scenarios is evaluated in terms of end-to-end delay and throughput of the system as a function of satellite orbits and UMTS configuration for a variety traffic applications (UDP/TCP) and traffic data rates. It is observed that Satellite-UMTS (S-UMTS) telecommunication networks provide acceptable delay and throughput performance. Also, due to the synergy that exists between satellite and UMTS networks, S-UMTS is a sound approach for delivering multimedia services globally.**

***Keywords*—*UMTS, Satellite, Orbit, Delay, Throughput.***

## I. INTRODUCTION

UMTS is a third generation cellular network, which is based on WCDMA technology, that provides 2 Mbps maximum data rate. It is structured into three main parts: the Radio Access Network (RAN), the Core Network (CN) and User Equipment (UE) [1]. All radio-related functionality is handled by RAN which includes Node B, base station, that converts the data flow between UE and CN through $I_{ub}$ and $U_u$ interfaces, and the Radio Network Controller (RNC) that controls the radio resources. UMTS is designed to provide world-wide, everywhere and anywhere, internet and multimedia services regardless of the users' position. At the same time, UMTS satellite component has been specified to provide complementary access with terrestrial network that offers promising opportunity for a fully integrated UMTS networks. Satellite-UMTS (S-UMTS) has the advantages of coverage extension capability and fast services deployment that contribute to global UMTS coverage and seamless services; such benefits are presented and discussed in [2]. According to the orbit planes, satellites are classified into three categories: Geostationary Earth Orbit (GEO), Medium Earth Orbit (MEO) and Low Earth Orbit (LEO). Each category has its own characteristics such as transmission delay, coverage area and constellation complexity. In this paper, all these three types have been used to evaluate the S-UMTS performance. Adaptation of UMTS to satellite environment and its constraints are approached in [4]; moreover, design of S-UMTS based on adaptation to terrestrial RAN specifications are discussed in [5] . In [6], end-to-end QoS concepts of S-UMTS, which includes delay and throughput, are presented. Zangar and Tabbane in [7] have analysed the performance of voice traffic in S-UMTS using Markov model for resource allocation. Also, the performance of end-to-end signalling for conference set up over S-UMTS in terms of blocking probability and set up delay over GEO satellite is investigated in [8]. In this paper, the whole link delay and the throughput for S-UMTS are investigated for GEO, MEO and LEO satellite constellations using NS tool. In the simulation, two different UMTS topologies are considered where the satellite is assumed to be a bent pipe and Node B, respectively. According to the users' requirements and applications, the simulation is done for several traffic rates and TCP/UDP data protocols.

The paper is organized as follows: In Section II, UMTS integration scenarios with three types of satellite orbits are introduced and the protocol stack for each scenario is illustrated. Section III is dedicated to the description of NS models and definition of network nodes. Numerical results of the proposed integration scenarios for different traffic protocols and rates are explained and discussed in section IV. Finally, the paper is concluded in Section V.

## II. S-UMTS INTEGRATION NETWORK ARCHITECTURE SCENARIOS

The integration of terrestrial-UMTS with satellite systems paves the way for global UMTS coverage. Several satellite orbital constellations have been proposed for S-UMTS [3]. As an illustration, LEO and MEO satellites provide short propagation delay; however, they require large number of satellites and hence high complexity in terms of inter-satellites' handover and large signalling tasks. On the other hand, GEO satellite has less system complexity but the transmission delay is long and user's terminal transmission power is high. Satellite characteristic and S-UMTS frequency band are summarized in [2][9]. Designing of S-UMTS depends on the integration of the UMTS components with those of the satellite segment; some integration approaches are discussed in [10]. In this paper,

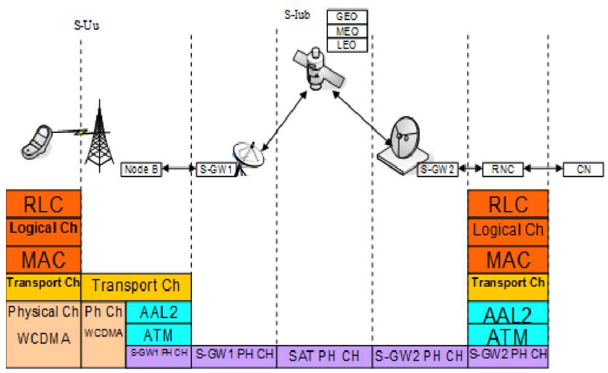


Fig. 1: Network Protocol and Architecture of Transparent Satellite Scenario

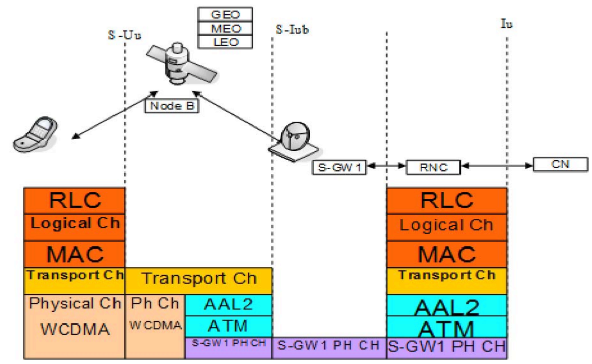


Fig. 2: Network Protocol and Architecture of Satellite as Node B Scenario

two scenarios have been used: 1) transparent Satellite (simple repeater) and 2) satellite as Node B. These are described below.

*1) Transparent Satellite :* In this scenario, the region that needs to be covered is remote with a considerable number of users. In order to deliver UMTS services to these regions, Node B is installed and then it is connected with RNC via satellite link. The satellite is regarded as a bent pipe, through which the traffic of Node B is transmitted transparently to terrestrial RNC over the $S\text{-}I_{ub}$ interface. The satellite component, which is used to adapt to the physical layer of RNC and Node B, consists of two gateways (S-GW1/S-GW2) and satellite channel represents the three orbit classes. Further details about protocal stack of UMTS can be found in [1]. The architecture of the transparent scenario with its protocol layers are shown in Fig.1. In this figure, it is shown that the extended satellite link is added in the lower layer of the UMTS protocol. The data traffic flows between ATM Adaptation Layers type-2 (AAL2) and the satellite physical channel. The advantages of this scenario are its simplicity of integration, where the integration is done without UMTS terrestrial component extension, and fast deployment of UMTS for coverage.

*2) Satellite As Node B:* Whenever wide area needs to be covered, and the investment of terrestrial Node B is futile, the Node B is implemented in the satellite segment. The satellite then acts as a link between UE and RNC. In this scenario, all radio functionality of Node B are performed on satellite board; however, it requires high power resources which is scarce on the satellite. To achieve complete connection, the UE is designed to operate as dual-mode terminal which has the capability to transmit directly to the satellite Node B over $S\text{-}U_u$ link that also requires more transmission power. On the other hand, roaming between terrestrial and satellite UMTS networks is a significant advantage of this scenario which provides seamless UMTS services particularly in a disaster situation. S-GW1 is used to connect the terrestrial RNC to the satellite Node B via $S\text{-}I_{ub}$ link that is implemented in the physical layer as illustrated in Fig.2.

## III. Simulation Models

Network Simulator (NS) is an important and reliable tool that has been widely used to investigate the performance of many telecommunication networks that are based on Internet Protocol (IP) [11]. In this work, the UMTS network is modified and combined with satellite component to create a complete telecommunication system using NS thereby system performance in terms of latency in the whole S-UMTS network and throughput can be investigated. The basic nodes of UMTS (UE, Node B, RNC and CN) and satellite nodes are defined and created in the simulation models. The simulation is conducted for the two proposed scenarios and different satellite orbits (GEO, MEO and LEO) where the satellite channel is assumed to be AWGN. The satellite (GEO, MEO and LEO) altitude is chosen as 36000km, 9000Km and 2000Km, respectively. The simulation model is used to connect both the source and sink, through the UMTS Core Network (CN) and S-UMTS network, using both scenarios, as shown in Fig.3 and Fig.4. For both scenarios (simple repeater/Node B), the simulation

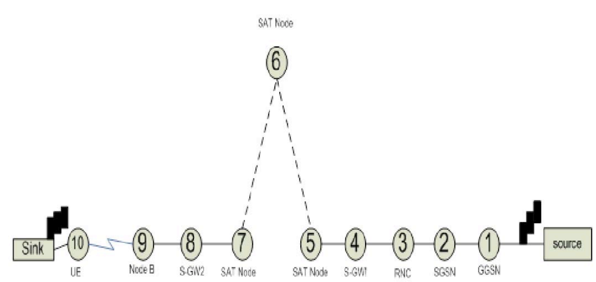


Fig. 3: Simulation Network Model with Satellite and Terrestrial Nodes for Transparent Scenario

was carried out for two different types of traffic protocols (UDP/TCP). Constant Bit Rate (CBR) was utilized to simulate the real time traffic whereas File Transfer Protocol (FTP) was applied for non real time traffic. The simulation was carried out using several source data rates (32 Kbps, 64 Kbps, 128 Kbps and 256 Kbps) and for each case the delay and throughput were measured. In the simulation model, the satellite segment was represented by nodes 5, 6 and 7 whereas the other nodes depicted the UMTS network as indicated in Fig.3 and Fig.4. The data traffic flow from the source, which connected node 1, upto the destination was linked to the UE. Hence, the overall link of integrated S-UMTS system was covered in the simulation.

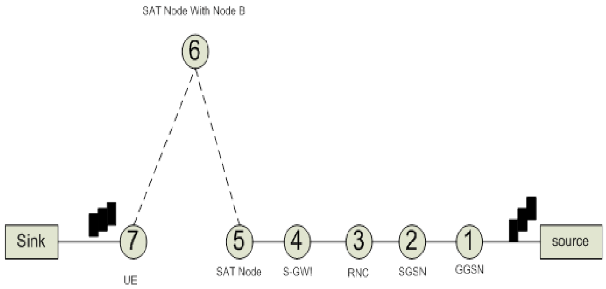


Fig. 4: Simulation Network Model with Satellite and Terrestrial Nodes for Node B Scenario

## IV. Simulation and Numerical Results

The following measurements were recorded: $i)$ end-to-end delay $ii)$ throughput. Delay was measured in the link between the source and the sink while the throughput was measured in the UE terminal. Both performance metrics were computed for two different types of IP traffic: CBR/UDP and FTP/TCP for several data rates. All three satellite orbits were considered for each proposed scenario.

### A. Delay Analysis

For the proposed scenarios in Section II, the simulation measurements were carried out by taking into consideration the UMTS delay components [12]; in addition, the satellite segment extra added delay to the S-UMTS which was also considered. The S-UMTS delay budget can be expressed as:

$$T_{\mathrm{EE}} = T_{\mathrm{ITC}} + T_{\mathrm{PPO}} + T_{\mathrm{MAC}} + T_{\mathrm{MDC}} + T_{\mathrm{AAL}} + T_{\mathrm{SAD}} + T_{\mathrm{SD}} \quad (1)$$

where $T_{\mathrm{ITC}}$ is the interleaving and turbo coding delay, $T_{\mathrm{PPO}}$ is the packetization, de-packetization and end-system play-out delay, $T_{\mathrm{MAC}}$ is the MAC scheduling delay, $T_{\mathrm{MDC}}$ is the macro-diversity combining delay, $T_{\mathrm{AAL}}$ is the AAL packetization, multiplexing and de-packetization delay, $T_{\mathrm{SAD}}$ is the satellite link delay and $T_{\mathrm{SD}}$ is the switch delay. All delay components in (1) were considered in the simulation measurements. For satellite transparent scenario, the end-to-end delay versus simulation time, for LEO and GEO satellites, are plotted in Fig.5 and Fig.6, where 128Kbps and 256Kbps UDP traffic were implemented, respectively.

It is apparent that the packet delay varies as a function of the simulation time and some packets experienced longer delay due to time spent in the network nodes. From Fig.6, it is observed that satellite altitude significantly impacts the total average delay that is referred to as the latency of GEO satellite link. The delay measurements for the proposed scenario 1 have been executed for various source rates. Thereby, the effect of source data rate on the average delay was investigated. Average delay of S-UMTS network is plotted in Fig.7 as function source data rate for the three satellite orbits. It is noted that the average delay slightly increased as the packet rate increased. To investigate the role of the performance of satellite segment for Node B scenario, round trip time for packets were measured for all three satellite orbits. Variation of packet delay versus simulation time are shown in Fig.8 and Fig.9. The average packet delay for various data rates and

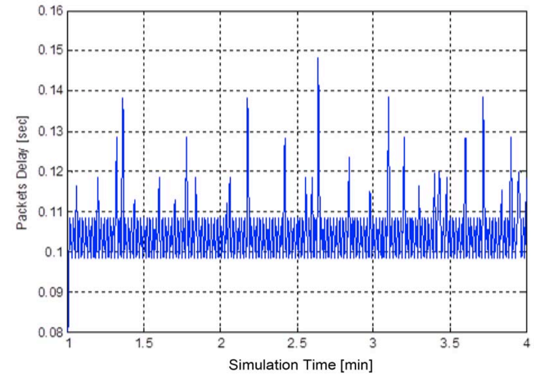


Fig. 5: UDP Delay versus Simulation Time for LEO Scenario 1 (128 Kbps)

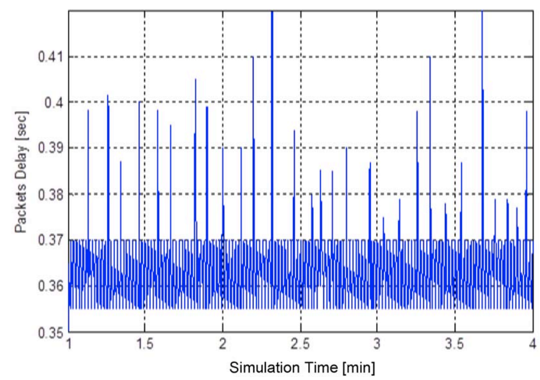


Fig. 6: UDP Delay versus Simulation Time for GEO Scenario 1 (256 Kbps)

satellite orbits is summarized in Table I. It is observed from Fig.8 that most of the packets arrived in the time-line between 135 msec and 153 msec while some of them were received late.

UMTS is designed for multimedia services and thus it is important to investigate the S-UMTS performance for TCP services. Hence, the total delay of TCP packets was measured using FTP protocol over different satellite orbits for a source rate of 256 Kbps. For scenario 1, the delay from node 1 upto node 10 was measured and plotted as shown in Fig.10. It is observed from this figure that TCP packets encountered longer delay than UDP packets. This is due to queuing, congestion and retransmissions delay associated with lost packets. Also, it is observed that packet loss rate in GEO is higher than in LEO and MEO. This is due to high bit error rate in GEO compared to LEO and MEO satellite channels. From Table I, it is noted that scenario 2 provides better delay performance; however, more power is required in satellite on board and UE. Moreover, it is known that the average round trip delay of S-UMTS over GEO satellite satisfies the QoS requirements [6][13].

### B. Throughput Analysis

The average delivered data rate was measured in UE (node 10) in bps which represents the throughput. Fig. 11 shows a sample of the simulation results, where the throughput performance was measured for the case of 32 Kbps CBR/UDP

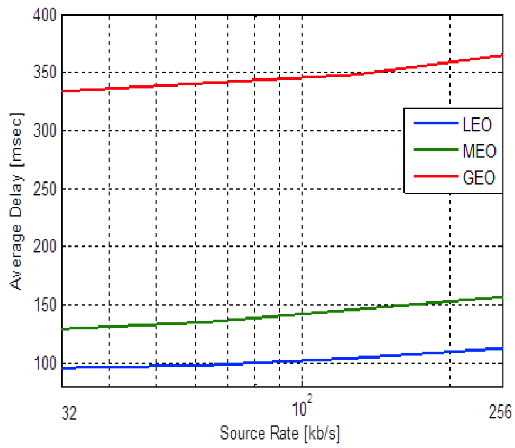


Fig. 7: Average Delay versus UDP Source Data Rate Scenario 1

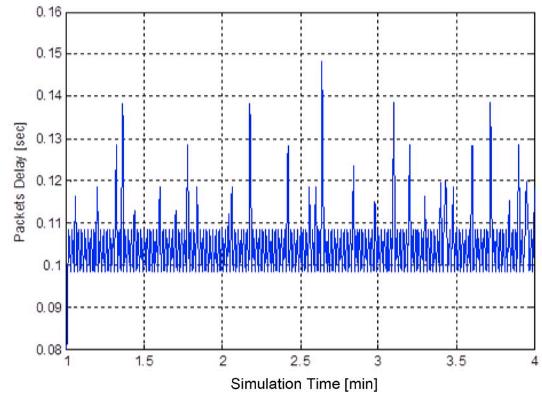


Fig. 9: UDP Delay versus Simulation Time for Scenario 2 GEO 128 Kbps

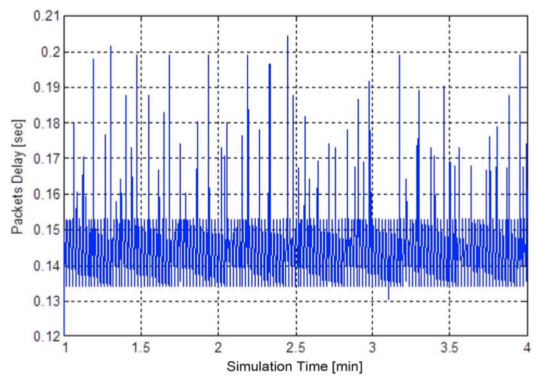


Fig. 8: UDP Delay versus Simulation Time for MEO Scenario 2 (256 Kbps)

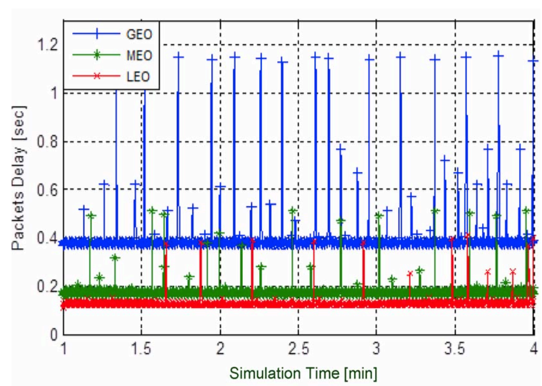


Fig. 10: TCP Delay versus Simulation Time of Scenario 1 LEO, MEO and GEO (256 Kbps)

TABLE I: Summary of Average Delay Measurements for the Proposed Scenarios and Three Satellite Categorises

| Orbits | Scenario | UDP[Kb/s] | Delay[msec] | TCP[Kb/s] | Delay[msec] |
|---|---|---|---|---|---|
| LEO | SC1 | 32 | 96.5 | | |
| | | 64 | 98.25 | 128 | 121 |
| | | 128 | 105 | | |
| | | 256 | 113 | 256 | 133 |
| | SC2 | 32 | 93 | | |
| | | 64 | 96 | 128 | 113 |
| | | 128 | 99 | | |
| | | 256 | 107 | 256 | 126 |
| MEO | SC1 | 32 | 130 | | |
| | | 64 | 135.5 | 128 | 166 |
| | | 128 | 146 | | |
| | | 256 | 157 | 256 | 178 |
| | SC2 | 32 | 121 | | |
| | | 64 | 128.5 | 128 | 153 |
| | | 128 | 135 | | |
| | | 256 | 147 | 256 | 171 |
| GEO | SC1 | 32 | 334 | | |
| | | 64 | 341 | 128 | 379 |
| | | 128 | 347.5 | | |
| | | 256 | 365 | 256 | 395 |
| | SC2 | 32 | 322 | | |
| | | 64 | 329 | 128 | 357 |
| | | 128 | 338.5 | | |
| | | 256 | 354.5 | 256 | 375 |

traffic during 1 min simulation time. It is noted that the throughput over GEO satellite channel is more influenced than

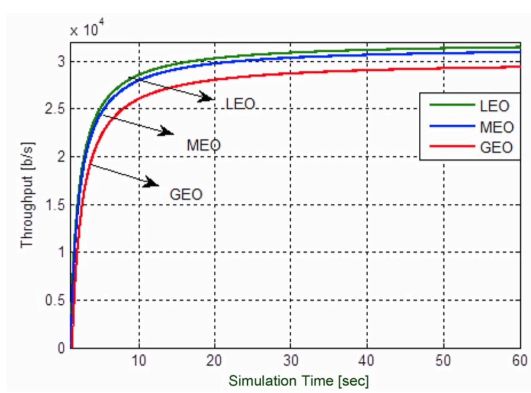


Fig. 11: Throughput of 32 Kbps of scenario 1 (LEO, MEO, GEO)

LEO and MEO satellite channels; however, the best throughput is achieved in the LEO case. Throughput was also investigated for the case of satellite on board Node B (scenario 2). In this case, the throughput performance was measured using 64 Kpbs data rate. The throughput performance comparisons between the two scenarios are shown in Fig. 12 and Fig. 13. From Fig.12, it is observed that scenario 1 provides better throughput performance relative to scenario 2. In terms of the

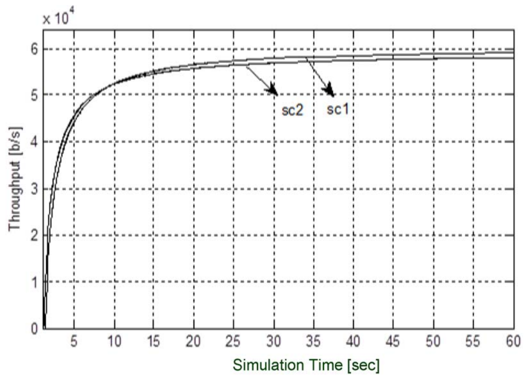


Fig. 12: Comparison of Throughput Between Scenario 1 and scenario 2 for GEO satellite orbit with 64 kbps

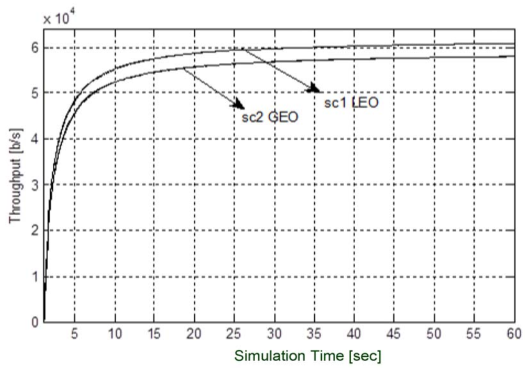


Fig. 13: Comparison of Throughput Between the Scenario 2 GEO and Scenario 1 LEO for 64 kbps

proposed scenarios and satellite orbits, the transparent scenario 1 for LEO provides the best throughput; in contrast, the worst throughput is observed for Node-B scenario with GEO satellite orbit.

## V. CONCLUSION

The synergy of satellite systems with those of terrestrial radio networks can provide a major leap toward global broadband wireless services; however, it has challenges that need to be overcome. In this paper, UMTS coverage extension using satellite systems has been investigated. Transparent satellite and Node B satellite scenarios with three protocol stacks have been presented. Using NS, the performance of S-UMTS has been evaluated in terms of packet delay for the overall network and the throughput at UE. Three common satellite constellations have been used in the simulation. The performance results show that expanding of UMTS coverage using satellite component is highly feasible. Also, it is noted that the traffic in the local Node B can be effectively managed to minimize the link delay and optimize the satellite bandwidth utilization by transmitting only the signalling part through the satellite link.

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