Performance Evaluation of TCP/IP over EDGE

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Abstract. Enhanced Data rates for Global Evolution (EDGE) provides an evolutionary path from existing cellular systems such as Global System for Mobile Communications (GSM) for delivering higher bit rate services that facilitate wireless Internet access. Thus, EDGE only defines a new radio access technology to achieve higher bit rates. This paper investigates the performance of Transmission Control Protocol/Internet Protocol (TCP/IP) over the enhanced packet-switched transmission mode of EDGE, i.e., Enhanced General Packet Radio Service (EGPRS). The Network Simulator (*ns*) tool was used in the simulation. The performance of TCP was examined under various channel conditions with and without the link adaptation scheme of EGPRS. The link adaptation scheme improves the TCP performance under poor channel conditions. In the simulation, two different methods, BLock Error Rate (BLER) and the average of measured Carrier-to-Interference ratio (C/I), were employed to determine the channel quality and subsequently to select the most appropriate coding scheme to maximize the TCP throughput. The TCP throughput obtained using the BLER method is higher under poor channel conditions, while the throughput based on the average of measured C/I out-performs BLER under good channel conditions. As a result, we proposed a hybrid method, which selects the BLER method for poor channel conditions and the average measured C/I for good channel conditions. The simulation results show that the throughput obtained using the hybrid method is superior compared to the individual method.

1 Introduction

Presently, the Global System for Mobile Communications (GSM) supports not only speech but data services with user bit rates up to 9.6 kbps. However, this data rate is not adequate for many Internet applications, especially those that have a large amount of traffic to transfer, such as a file transfer. To ameliorate this situation, the European Telecommunications Standards Institute (ETSI) has standardized High Speed Circuit Switched Data (HSCSD) [1] and General

*** CWC is a national R & D centre funded by the Singapore National Science and Development Board.

Packet Radio Service (GPRS) [2] to achieve higher bit rate. Both standards are evolved from the GSM technology. Since HSCSD and GPRS are based on the original Gaussian Minimum Shift Keying (GMSK) modulation, the increase of bit rate is moderate and below the International Mobile Telecommunications in Year 2000 (IMT-2000) requirement set by International Telecommunication Union (ITU), which is 384 kbps for high-users mobility with wide-area coverage. Thus, ETSI is developing the Enhanced Data rates for Global Evolution (EDGE) [3] to enhance both circuit-switched and packet-switched transmission modes of GSM. The enhancements defined in EDGE are basically in the physical and data link layers to efficiently providing the required bit rate. EDGE reuses existing GSM/GPRS infrastructure including carrier bandwidth and Time Division Multiple Access (TDMA) structure.

The Internet is the most popular and widely used packet-switched network that provides applications like File Transfer Protocol (FTP), World Wide Web (WWW), Email, etc. These Internet applications rely on two commonly used protocols, namely, Transmission Control Protocol and Internet Protocol (IP) (TCP/IP) [4], to reliably transport data across heterogeneous networks. IP is concerned with routing data from source to destination host through one or more networks connected by routers, while TCP provides a reliable end-to-end data transfer service. A number of studies can be found in the literature (e.g., [5, 6]) have shown that TCP performs poorly over wireless links. However, these studies are primarily focused on Wireless Local Area Networks (WLANs), e.g., WaveLAN. WLANs are differed from cellular networks such as EDGE in a number of ways. Firstly, EDGE provides sophisticated and reliable radio and link layers. Secondly, EDGE is for wide-area coverage and high-speed user mobility. As the main goal of EDGE is to provide wireless Internet access, it is important to evaluate the performance of TCP over EDGE. This paper evaluates the performance of TCP over EDGE through a simulation study using the Network Simulator (*ns*) [7] jointly developed by the University of California - Berkeley, University of Southern California (USC) and Xerox PARC.

2 Overview of EDGE

EDGE [3] provides an evolutionary path from Second-Generation (2G) systems (such as GSM) for delivering Third-Generation (3G) services including Internet access, which demand higher bandwidth and quality. As such, EDGE only defines a new radio access technology to achieve higher bit rates and reuses the infrastructure of GSM/GPRS. The parts in the GSM/GPRS system, which are affected by EDGE introduction, are the Mobile Station (MS) and the Base Station Subsystem (BSS), as illustrated in Fig. 1. EDGE offers enhancements to packet-switched and circuit-switched transmission modes of GSM, which refer to as *Enhanced GPRS (EGPRS)* and *Enhanced Circuit-Switched Data (ECSD)* [8], respectively. EGPRS is the main focus of this paper because it offers packet services and higher user bit rates than ECSD.

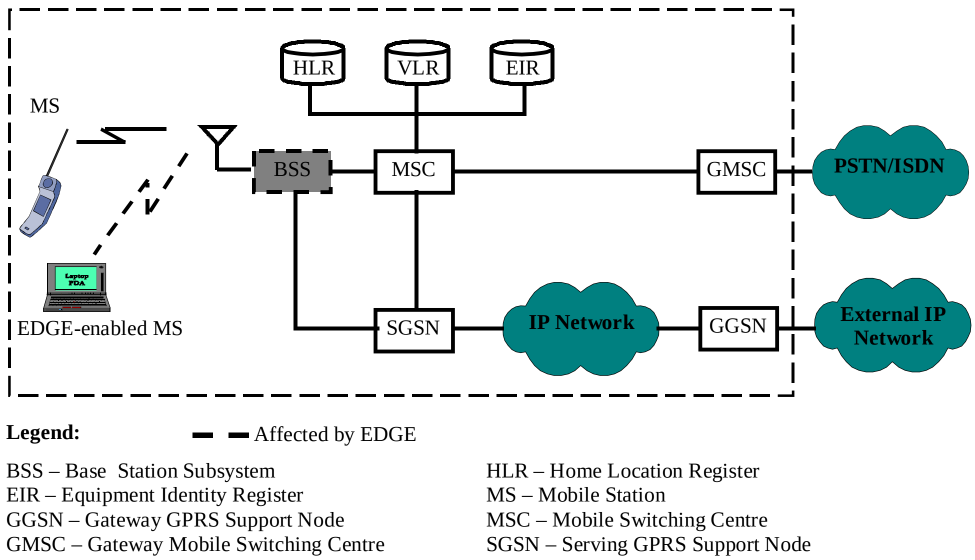


Fig. 1. EDGE Architecture

In order to increase the radio gross bit rate, a linear high-level modulation, i.e., 8-Phase Shift Keying (8-PSK) is introduced for EDGE. 8-PSK is chosen because it provides high data rates and high spectral efficiency. Many EDGE physical layer parameters are identical to those of GSM. The carrier spacing is 200kHz and GSM's TDMA frame structure is unchanged. Also, the GSM burst structure and period, which is equal to $576.92 \mu sec$ remained.

In addition to the physical layer, EDGE also makes enhancements to the Radio Link Control (RLC) protocol. EDGE RLC protocol is somewhat different from the corresponding GPRS RLC protocol due to higher bit rate and the need to adapt the data protection to channel quality. The main changes are related to improvements in link quality control scheme. Presently, EDGE includes two link quality control techniques [3], namely, *Link Adaptation* (LA) and *Incremental Redundancy* (IR).

The LA scheme estimates the link quality and subsequently selects the most appropriate coding scheme for coming transmissions in order to maximize the throughput. EDGE defines six different coding schemes (PCS-1 to PCS-6) on top of those of GPRS (CS-1 to CS-4) as described in Table 1. The coding schemes have different radio interface rates and robustness, and are therefore optimal for use in different link quality regions. The LA scheme ensures that the most efficient scheme is always selected. In other words, a more robust scheme is employed for bad channel conditions and a less robust one (e.g., PCS-6) for good channel conditions. LA requires feedback information from the receiver to the transmitter about the link conditions in order to select the most appropriate

Table 1. Channel Coding Schemes for EGPRS/EDGE

Coding Scheme	Code Rate	Modulation	Radio Interface Rate per Timeslot
PCS-1	0.33	8-PSK	22.80 kbps
PCS-2	0.50	8-PSK	34.30 kbps
PCS-3	0.60	8-PSK	41.25 kbps
PCS-4	0.75	8-PSK	51.60 kbps
PCS-5	0.83	8-PSK	57.35 kbps
PCS-6	1	8-PSK	69.20 kbps
CS-1	0.49	GMSK	11.20 kbps
CS-2	0.64	GMSK	14.50 kbps
CS-3	0.73	GMSK	16.70 kbps
CS-4	1	GMSK	22.80 kbps

coding scheme. Normally, such information consists of parameters such as mean Carrier-to-Interference ratio (C/I) or Signal-to-Noise Ratio (S/N). In the simulation study, we use the C/I parameter to determine the link quality. However, it is impossible to know C/I beforehand, and can only be estimated. Two different methods [9] can be employed to estimate C/I and both methods were used and compared in the simulation.

In the first method, the C/I is estimated by averaging the measured C/I over the latest polling interval, which is a number of RLC blocks. This estimation is used to select the coding scheme providing the highest throughput for the given C/I. The throughput (S_n) per time slot for each coding scheme, n, can be determined from the following equation [10]:

$$S_n = R_n.(1 - BLER_n(C/I)) \tag{1}$$

where the radio interface rates (R_n) are given in Table 1, and the BLock Error Rate ($BLER_n$) for a given C/I can be obtained from [11]. The task of LA is to always select the coding scheme, n, which maximizes S_n according to Eq.(1). The second method uses $BLER$ to indicate the C/I level. For each polling interval, the $BLER_n$ for the coding scheme, n, is computed as follows:

$$BLER_n = \frac{Number\,of\,Erroneous\,Blocks}{Total\,Number\,of Blocks\,per\,Interval} \tag{2}$$

If the $BLER_n$ lies above a certain threshold, a more robust coding scheme than the current one should be used, otherwise a weaker scheme should be chosen. Both methods always start with the weakest coding scheme, i.e., PCS-6.

In the IR scheme, information is first sent with very little coding, yielding a high bit rate if decoding is immediately successful. If if decoding fails, additional coded bits are sent until decoding succeeds. As a result, the bit rate is lower and the delay increases.

3 Simulation Environment

As mentioned, the focus of the paper is on the enhanced packet-switched transmission mode of EDGE, i.e., EGPRS for wireless Internet access. Thus, the performance of TCP is simulated over EGPRS. The simulation was carried out using the *ns* and its wireless extensions from the Carnegie Mellon University's MONARCH Project [12]. The network configuration used for the simulation study is depicted in Fig. 2(a), which shows end-to-end communications between a single MS and a Fixed Host (FH). Each of the logical entities in the configuration can be realized as an *ns* node and links are defined to connect these nodes. As illustrated in Fig. 2(b), the FH, GGSN, and SGSN were defined as *ns* wired nodes, which in turn connected by duplex links. The BSS and MS were defined as *ns* wireless nodes and they are linked via a wireless channel.

Delays and packet losses introduced by the IP network can be modelled in *ns* by attaching an Error Model (see Fig. 2(b)) on the link between FH and GGSN. The model specifies the link mean packet loss rate and mean delay.

The protocol layers defined for each node is shown in Fig. 2(c). The application layer was implemented by attaching an application object, e.g., FTP, to the TCP agent defined for the end nodes (MS or FH). In the simulation, the FTP object was defined at FH to support uni-directional transfer of bulk data from FH to MS. TCP Agents (source or sink) were defined at the end nodes to implement end-to-end flow control. In the simulation, one-way TCP Tahoe version was used. The EDGE and TCP/IP parameters used in the simulation are summarized in Table 2.

Table 2. Simulation Parameters

Parameter	*Value*	*Parameter*	*Value*
Simulation Time	2000 seconds	C/I range	6 - 30 dB
TCP version	Tahoe	RLC Polling Interval	10 blocks
TCP Packet Size	512 bytes	Frequency Hopping	Ideal
TCP Window Size	16 segments	Modulation Schemes	8-PSK, GMSK
Mean Internet Delay	100 s	Number of Timeslot(TS)	1
Mean Internet Loss	0.01	Number of MS	1
Coding Schemes	PCS-1 to PCS-6, CS-1 to CS-4	Environment	Typical urban, low mobility (user speed 3km/hr)

4 Simulation Results and Observations

End-to-end TCP performance over EGPRS was evaluated for bulk data transfer from FH to MS based on the scenario in Fig. 2(a) under various channel conditions. Trace agents were attached to the TCP source and sink so that arrival and departure time of each packet was recorded on the packet header. The

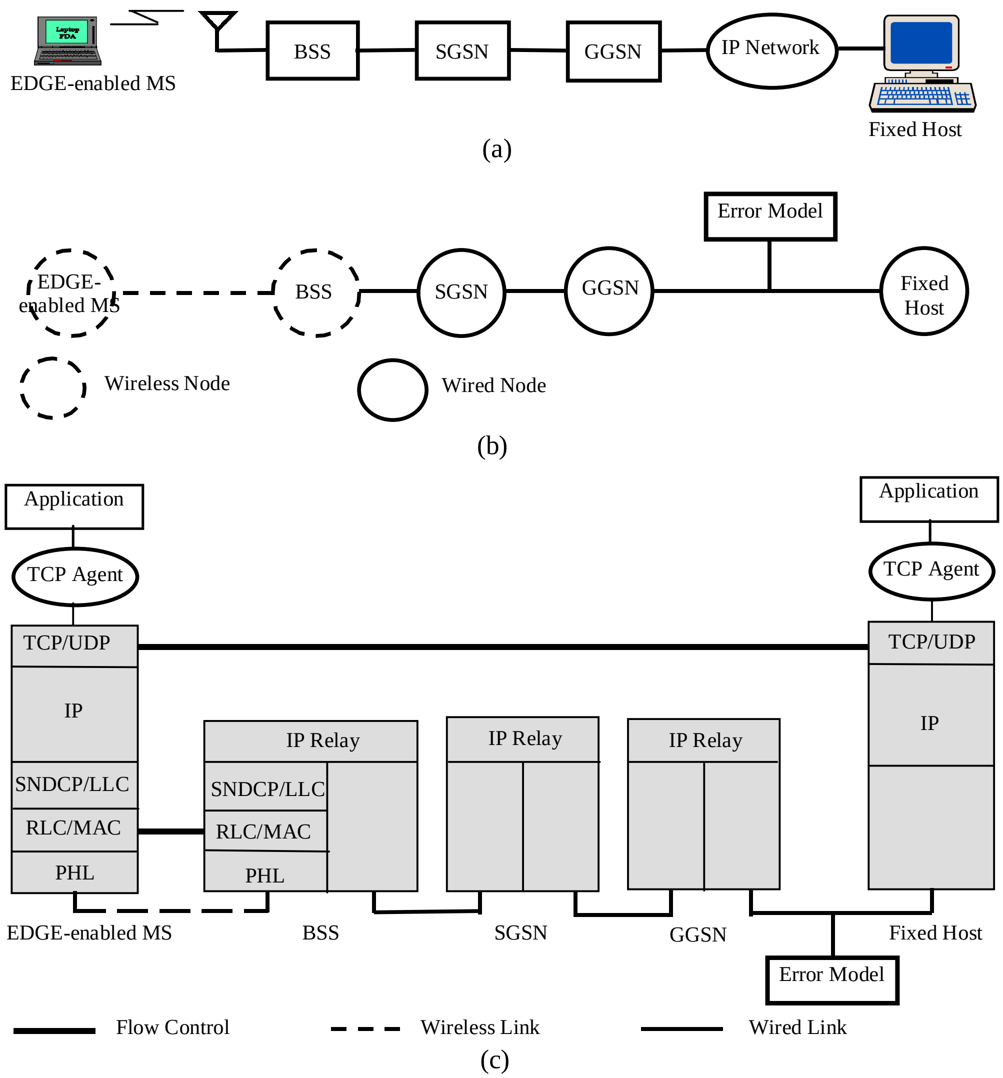


Fig. 2. (a) Top-Level Simulation Environment; (b) Realization of the Top-Level Simulation Environment in *ns*; (c) Protocol Structure in *ns*

TCP *throughput* is then computed from the trace output. In the simulation, the *throughput* was measured for each EGPRS coding scheme under various channel conditions with and without the LA scheme. Firstly, we will consider the throughput without the LA scheme. Fig. 3(a) depicts the simulated throughput without the LA scheme and Fig. 3(b) illustrates the theoretical throughput determined using Eq.(1). By comparing Figs. 3(a) and 3(b), the simulated throughput levels are significantly lower than the corresponding theoretical values under all channel conditions. This is because the throughput computed using Eq.(1) assumes that most of the RLC blocks are successfully transmitted on the first attempt. However, for EGPRS coding schemes, which are highly sensitive to noise, significant retansmissions occur that can contribute to additional latency, resulting in throughput degradation. If we take latency into account then Eq.(1) can be re-written as follows:

$$S_n = \frac{R_n.(1 - BLER_n(C/I))}{(1 + BLER_n(C/I))} \tag{3}$$

The theoretical throughput, which is computed using Eq.(3) is shown in Fig. 3(c) and the peak throughput levels under good channel conditions are in agreement with the simulated throughput as in Fig. 3(a).

For the throughput performance with the LA scheme, there are two methods that can be used to estimate C/I as described in Section 2. Both methods were considered in the simulation. Figs. 4(a) and 4(b) depict the throughput obtained by averaging the measured C/I and BLER, respectively. In addition, both figures show the maximum simulated throughput in the case of ideal link adaptation, which is determined by selecting the maximum throughput at each C/I over all the coding schemes. For the case where C/I is estimated by averaging the measured C/I, the throughput approximates the performance of the ideal link adaptation under very good channel conditions (when $C/I > 25$ dB) but fails to deliver useful throughput as channel conditons deteriorate. The BLER method, on the other hand, achieves throughput performance of the ideal link adaptation for bad channel conditions (when $C/I < 12$ dB) but unable to reach the ideal link adaptation performance when channel conditions improve.

Hence, we propose a hybrid method, which selects the BLER method for bad channel conditions and the average measured C/I method for good channel conditions. The throughput obtained using this hybrid method is plotted in Fig. 4(c) and compared with the average measured C/I and BLER. As shown in the figure, the throughput performance of the hybrid method is superior compared to the individual method.

5 Conclusions

EDGE is a radio-access technology capable of providing wireless Internet access within the framework of 3G. It reuses GSM technology and offers higher bit rates. In this paper, we investigated the performance of TCP/IP over EDGE using the *ns* simulation tool. We presented the simulated TCP throughput results with and

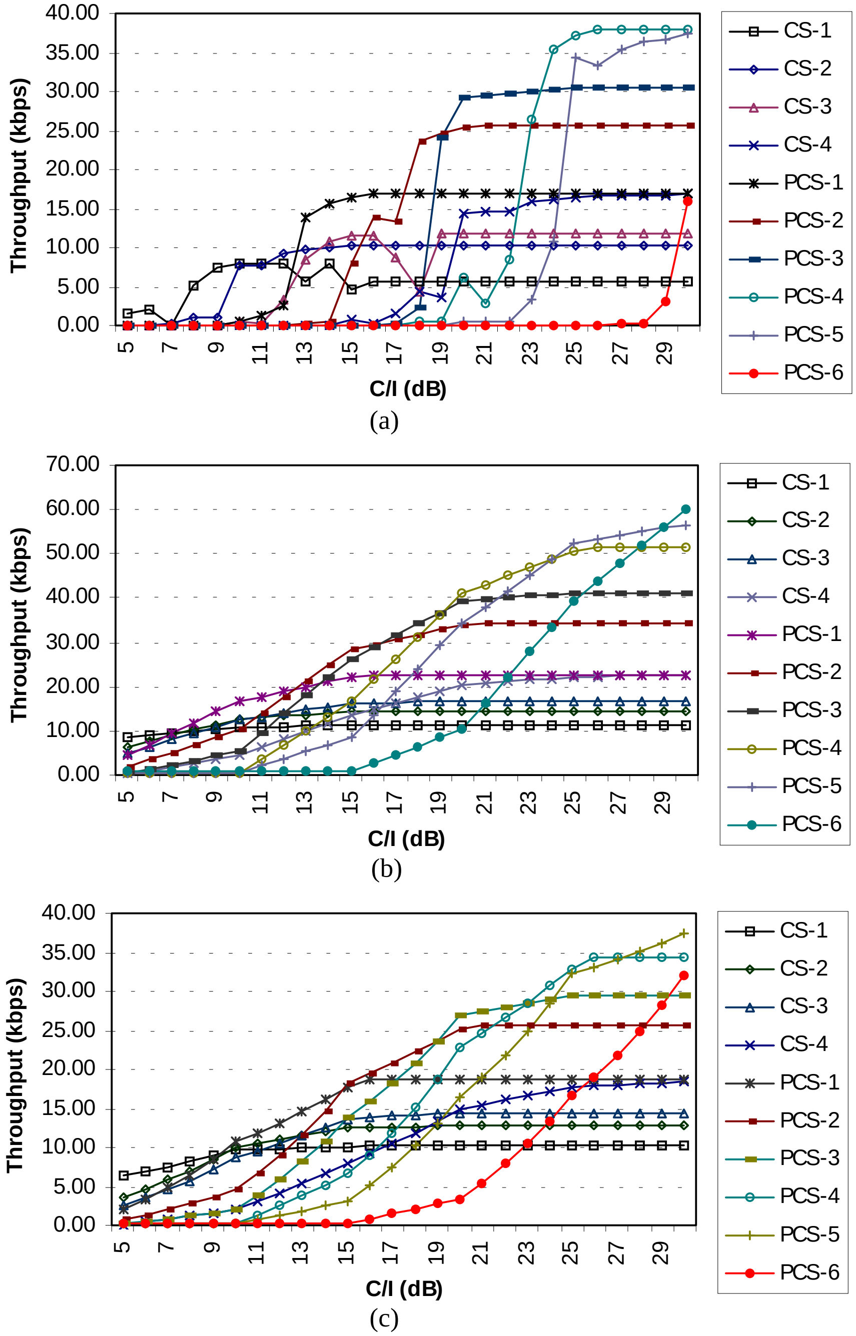
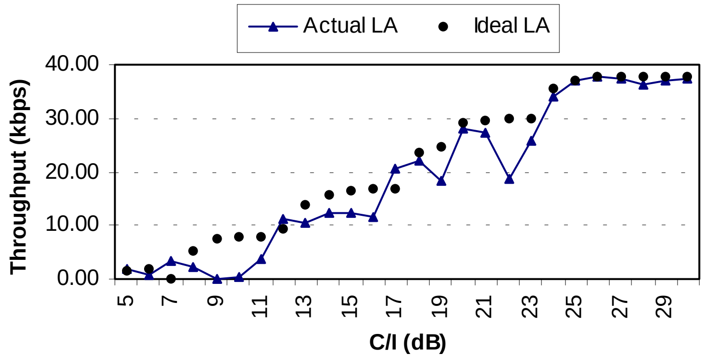
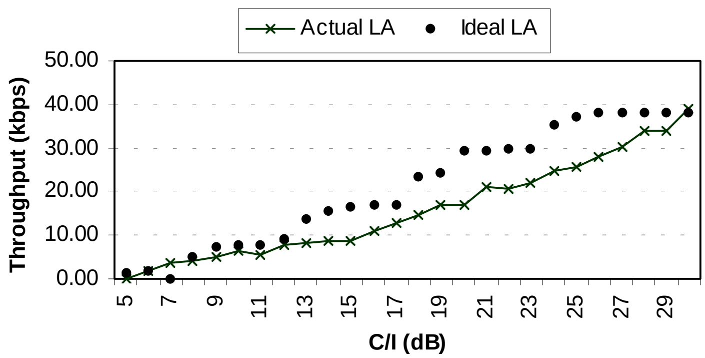


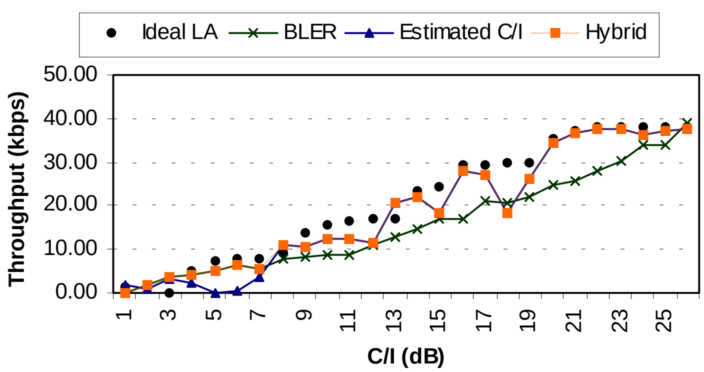
Fig. 3. (a) Simulated Throughput; (b) Theoretical Throughput (computed using Eq.(1)); (c) Theoretical Throughput (computed using Eq.(3))



(a)



(b)



(c)

Fig. 4. (a) Simulated Throughput obtained using Estimated C/I Method; (b) Simulated Throughput obtained using BLER Method; (c) Simulated Throughput obtained using Hybrid Method

without the link adaptation scheme and compared with the theoretical results. The simulated throughput results without link adaptation scheme are comparable to the theoretical one. However, the throughput deteriorates under poor channel conditions. Hence, the link adaptation scheme is designed to cope with poor channel conditions. The link adaptation scheme uses the C/I parameter to determine the link quality and subsequently selects the most appropriate coding scheme. In the simulation, the link adaptation employs two methods, BLER and the average of measured C/I, to determine the link quality. The throughput obtained using the BLER method is higher under poor channel conditions. On the other hand, the average measured C/I out-performs BLER under good channel conditions. As a result, we proposed a hybrid method, which selects the BLER method for poor channel conditions and the average measured C/I for good channel conditions. The simulation results show that the throughput obtained using the hybrid method is superior to the individual method.

References

1. ETSI. *GSM 03.34: Digital Cellular Telecommunications System (phase 2+); High Speed Circuit Switched Data (HSCSD); Stage 2*, 1997.
2. ETSI. *GSM 03.64: Digital Cellular Telecommunications System (phase 2+); General Packet Radio Service (GPRS); Overall Description of the GPRS Radio Interface; Stage 2*, 1998.
3. A. Furuskar et al. "EDGE: Enhanced Data Rates for GSM and TDMS/136 Evolution". *IEEE Personal Communications Magazine*, pages 56–66, June 1999.
4. W. Stevens. *TCP/IP Illustrated, Vol. 1.* Addison Wesley, Reading, MA, 1994.
5. R. Caceres and L. Iftode. "Improving the Performance of Reliable Transport Protocols in Mobile Computing Environments". *IEEE Journal on Selected Areas in Communications*, 13(5):850–857, 1995.
6. S. Seshan H. Balakrishnan and R. Katz. "Improving Reliable Transport and Hand-off Performance in Cellular Wireless Networks". *ACM Wireless Networks*, 1(4), 1995.
7. K. Fall and K. Varadhan. ns *Notes and Documentation.* LBNL, January 2000. http://www-mash.cs.berkeley.edu/ns.
8. S. Hamiti et al. "EDGE Circuit Switched Data - An Enhancement of GSM Data Services". In *IEEE Wireless Communications and Networking Conference*, pages 1437–1441, September 1999.
9. O. Qeuseth et al. "Algorithms for Link Adaptation in GPRS". In *IEEE Vehicular Technology Conference (VTC)*, pages 943–947, May 1999.
10. A. Furuskar et al. "System Performance of EDGE, a Proposal for Enhanced Data Rates in Existing Digital Cellular Systems". In *IEEE Vehicular Technology Conference (VTC)*, pages 1284–1289, May 1998.
11. UWCC. *UWC-136 RTT Update.* TR45.3/98.04.06.07R4, February 1999.
12. Carnegie Mellon University. *The CMU Monarch Project's Wireless and Mobility Extensions to* ns, August 1999. http://monarch.cs.cmu.edu/cmu-ns.html.