SIMULATING CDPD NETWORKS USING OPNET

Michael Jiang, Stephen Hardy, and Ljiljana Trajkovic*
School of Engineering Science
Simon Fraser University
Vancouver, British Columbia
Canada V5A 1S6
{zjiang, steve, ljilja}@cs.sfu.ca
http://www.ensc.sfu.ca/research/cnl

Abstract
In this paper we describe simulation of wireless data networks using OPNET. We give a detailed description of the network model that we used to investigate the impact of self-similar traffic on performance of a cellular digital packet data (CDPD) network. We use OPNET Modeler and its object-oriented modeling approach and graphical editors to model and simulate the CDPD network of a local commercial service provider (Telus Mobility). In our simulations, we use genuine traffic traces collected from the Telus Mobility CDPD network. Our simulation results indicate that genuine traffic traces produce longer queues and, thus, require larger buffers in the deployed network's switching elements.

Index Terms – wireless networks, mobile networks, CPDP networks, network simulation, OPNET, traffic modeling, self-similarity, long-range dependence.

1. Introduction

Traffic patterns generated by voice, data, image, and video services that are available in current packet data networks, differ from patterns observed in circuit switched voice networks. Simulating these services requires traffic models that differ from traditional Poisson models used for voice traffic. Hence, users may experience poor performance due to incorrect traffic assumptions when provisioning and designing data networks.

Interest in self-similar traffic was first stimulated by the measurements of Ethernet traffic at Bellcore [9]. The analysis of the collected traffic traces led to the discovery that “traffic looks the same on all time scales” [10, 20, 21], and the introduction of the term self-similar (or fractal) traffic. Since then, this feature has been discovered in many other traffic traces, such as Transmission Control Protocol (TCP) [14-16], Motion Pictures Experts Group (MPEG) video [6], World Wide Web [4, 12], and Signaling System 7 [5] traffic. An important characteristic of self-similar traffic is its long-range dependence, i.e., the existence of correlations over a broad range of time scales [2, 3, 17].

Until now, most network traffic measurements were performed on wired networks. The question arises whether the traffic in wireless data networks exhibits self-similar behavior as well. If so, it is important to determine if this traffic characteristic affects the provisioning and design of wireless data networks.

To answer these questions, we analyzed traffic of a CDPD [1, 19] network of a local mobile data service provider (Telus Mobility, formerly BCTel). Our initial statistical analysis results indicate that these traces exhibit a certain degree of self-similarity. This long-range dependent behavior is statistically different from the traffic generated by traditional traffic models. In order to evaluate the performance of CDPD wireless networks, we use the OPNET tool [7] to simulate the Telus CDPD network. In our simulations, we use genuine traffic traces collected from the Telus network. Our simulation results indicate that genuine traffic produces longer queues. Hence, it requires larger buffers in the network's switching elements than traffic generated by traditional models.

The rest of this paper is organized as follows. In Section 2, we give the description of the OPNET CDPD network model. In Section 3, we present the simulation results. We conclude with Section 4.

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2. Simulation of the CDPD network

CDPD [1, 19] is a standard protocol developed for mobile data networks. It is a multiple access protocol in which stations that want to transmit data into the network must compete for access in the shared communications medium. CDPD shares some characteristics of more familiar multiple access protocols, such as Ethernet (IEEE 802.3), while still having significant differences. CDPD differs from other multiple access protocols in two ways: the wireless transmission medium and the mechanism for collision detection.

Topology of a simple CDPD network is shown in Fig. 1. Only the media access control (MAC) layer of the CDPD protocol is presented. Also shown are a mobile data intermediate system (MD-IS) or mobile router, and several fixed end stations (F-ES) connected to the wired network.

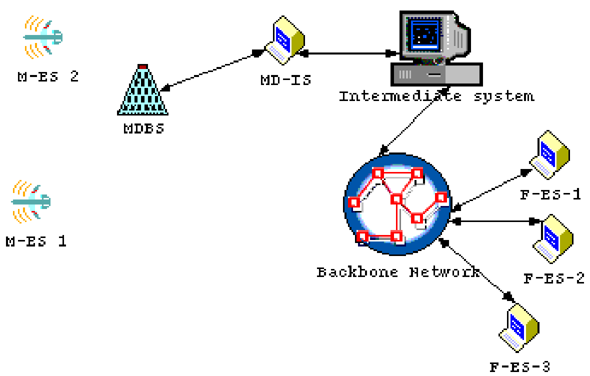

Fig. 1. Topology of a CDPD network. Each mobile end station (M-ES) is connected to the backbone network through the mobile data base station (MDBS). Fixed end systems (F-ES) are connected to the wired backbone network.

2.1 CDPD air interface network model

In the network model of the air interface, shown in Fig. 2, each M-ES generates data packets according to the genuine trace collected from the operational CDPD network, or more traditional traffic models from the OPNET libraries, such as Poisson and Gaussian models. The MDBS arbitrates activities on the channels it hosts at the MAC sub-layer, much like an Ethernet hub.

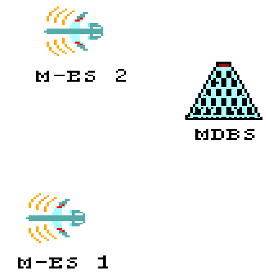

Fig. 2. Network model for the air interface. The two M-ES's send packets to the MDBS via the reverse channel at a center frequency of 825 MHz. They receive packets from the MDBS via the forward channel at a center frequency of 870 MHz.

2.2 Node models

The M-ES model shown in Fig. 3 is composed of a radio receiver and a radio transmitter, both operating at 19.2 kbps. The center frequency of the transmitter (reverse channel) is 825 MHz, with a bandwidth of 30 kHz. The center frequency of the receiver (forward channel) is 870 MHz, with a bandwidth of 30 kHz.

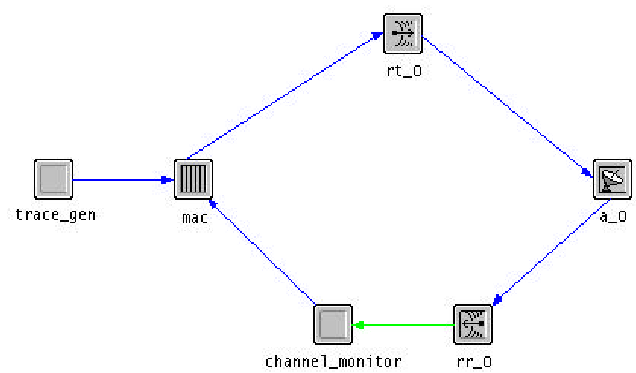

Fig. 3. Node model for mobile end system (M-ES). The radio transmitter is operating at a center frequency of 825 MHz. The radio receiver is operating at a center frequency of 870 MHz. Both have bandwidth of 30 kHz.

The generator (trace_gen) generates packets according to a genuine traffic trace. It can also employ the traffic traces generated by bursty ON/OFF traffic model or traditional traffic models supported by OPNET libraries. Using various traffic models, we investigated delay and buffer overflow probability of CDPD network.

The processor (mac) includes the digital sense multiple access (DSMA) logic. It retrieves the information about the reverse channel from the forward channel (*busy/idle* and *decode status* flags). If the reverse channel is busy or a collision occurs, the M-ES will back up for a random time period and try to retransmit again. The M-ES model also destroys the packets it has received.

The MDBS node model shown in Fig. 4 is more complex. It is connected to the external network (the wired part of a CDPD network) with a transmitter/ receiver pair. It receives packets from the M-ES via the radio receivers operating at a center frequency of 825 MHz (reverse channel), and transmits packets via the radio transmitters at a center frequency of 870 MHz (forward channel). The MDBS model also includes a processor that implements the digital sense multiple access (DSMA) logic for the MDBS. It sets the *busy/idle* and *decode status* flags on the forward channel according to the status of the reverse channel. The MDBS also receives the packets and collects certain statistics, such as the RF power level, bit error rate (BER), signal-to-noise ratio (SNR), and end-to-end delay.

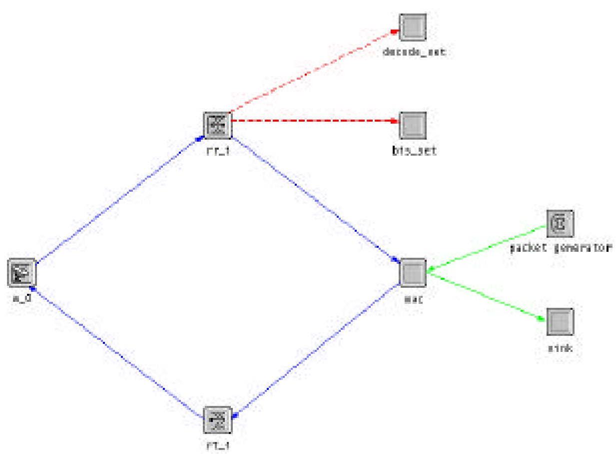

Fig. 4. Mobile data base station (MDBS) node model. This is the interface between the wireless and the wired sections of a CDPD network.

In the radio transceiver pipeline, used to transmit packets between transmitters and receivers, we implemented a Rayleigh fading channel model [8]. This model takes into account the interferences between the signal and reflection from surrounding obstacles, as well as the Doppler effect. This improved pipeline model enables us to simulate more realistic wireless environments by introducing bursts of bit errors in the transmitted packets, and by directly specifying the BER and the burstiness of the errors in the channel.

2.3 Process models

2.3.1 Process model of the M-ES

The finite state machine (FSM) of cdpd_mes_mac process model, shown in Fig. 5, performs media access control for the CDPD MAC interface in an M-ES. The role of cdpd_mes_mac is to accept data packets from higher layer protocols, to encapsulate this data into MAC frames, and to transmit these frames through the reverse channel to the MDBS using first-in-first-out scheduling scheme.

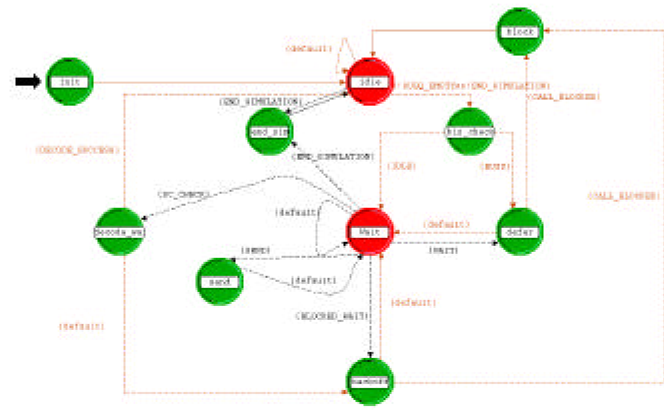

Fig. 5. FSM of cdpd_mes_mac process model. It performs media access control for the CDPD MAC interface in an M-ES.

After initializing the state variables, the FSM waits in the state "idle" for a packet arriving from the upper layer protocol. Once a packet arrives, the packet will be encapsulated to a sequence of blocks (with fixed length of 378 bits) and the FSM transitions to the state "bis_check". In this state, the FSM will check the *bis_flag* on the forward channel. Value *bis_flag* = 0 indicates that the reverse channel is idle. Data transmission can commence by a transition to the state "wait", and by waiting a MIN_WAIT_TIME before sending out the block. MIN_WAIT_TIME is a configurable system parameter with a default value of 0. If the *bis_flag* indicates that the reverse channel is busy, the FSM will transit to "defer" state. In the "defer" state, the M-ES performs a random backoff and tests the *bis_flag* again. The M-ES FSM will be in the "backoff" state when attempting to retransmit one or more blocks that have been marked as a decode failure by the MDBS. When the M-ES enters the "send" state, it transmits a block through the reverse channel. State "decode_wait" is a temporary state in which the M-ES waits a brief duration of time in order to determine whether the last block of its last transmission was successfully received by the MDBS or not. Time allocated for “decode_check” is 7 microslots (21.875 ms). The FSM reaches the “block” state if the last packet was unable to be transmitted. In this state the FSM discards the packet and returns to the “idle” state waiting for the arrival of the next packet. When the FSM receives the “end of simulation” event generated by the simulator, it transits to the “end_sim” state, returns control back to the simulator, and releases the memory.

2.3.2 Process model of the MDBS

The MAC module (mdbs_mac) of the MDBS node model is shown in Fig. 6. It is the peer part of the cdpd_mes_mac module inside the M-ES. MDBS has continuous access to the reverse channel stream. MDBS notifies the listening M-ES’s of the presence of data on the reverse channel. It performs notification of the decode status of the incoming data blocks from the reverse channel by using the *busy/idle* and the *decode status* flags in the forward channel stream.

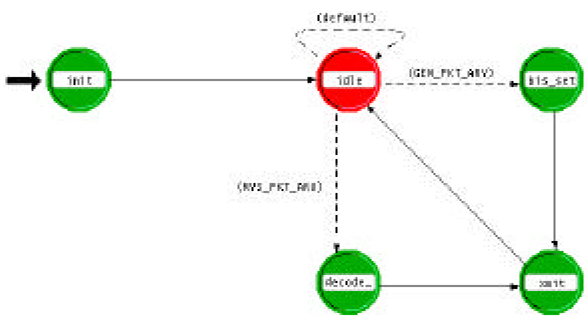

Fig. 6. FSM of the mdbs_mac process model inside the MDBS node model. This process model implements the MAC protocol for the MDBS.

Detection of data on the reverse channel must be implemented so that M-ES transmissions within 8 bit times of the last bit of an *idle* flag should result in setting the next *busy/idle* flag. In our model, we set the M-ES transmission time equal to zero. After receiving the data block from the reverse channel, MDBS decodes the data within two microslots and sets the next *decode status* flag with the result. Once the flag is set to indicate successful decode, it remains in that state until a decode failure occurs.

In the FSM of mdbs_mac process model, “init” state initializes the variables and then transitions to the “idle” state. In the “idle” state, the MDBS monitors the status of the reverse channel, and, based on the outcome, sets the *busy/idle* flag in the ”bis_set” state. The MDBS also monitors the decode status of the incoming data blocks from the reverse channel, and sets the *decode status* flag in the “decode_set” state. The *busy/idle* and *decode status* flags are then sent to the forward channel. In the “xmit” state, the MDBS sends the packet on the forward channel and discards the packet received from the reverse channel.

2.3.3 Process model for trace-driven sources

To run a trace-driven simulation, we need to input the actual CDPD network traffic trace into the network model shown in Fig. 7. This is achieved by the cdpd_trc_gen process model, where measured traffic traces were read into the model from files and converted to the format that OPNET can recognize.

Fig. 7. FSM of cdpd_trc_gen process model inside M-ES. This process model incorporates a loop where it keeps sending packets out to the network according to the information (packet arrival time and packet size) read in from traffic trace files.

The state “init” initializes the variables and loads the genuine traffic data into a structure called “list”. It examines the first line of the list to obtain the arrival time and packet size for the first frame. It creates a frame with the packet size and sets up a self-interrupt at the arrival time. Then, the cdpd_trc_gen FSM transits to the “idle” state. In the “idle” state, when a self-interrupt happens, M-ES first transmits to the cdpd_mes_mac the first frame generated by the “init” state. The next packet data length and the arrival time are generated according to the values on the next line of the list. The generated packet is then forwarded to cdpd_mes_mac, and “idle” schedules another packet arrival (i.e., self-interrupt) before going back to sleep.

2.3.4 Process model for ON/OFF traffic sources

The ON/OFF model [18] shown in Fig. 8 generates a statistical process with the same mean as the genuine trace collected from the actual CDPD network.

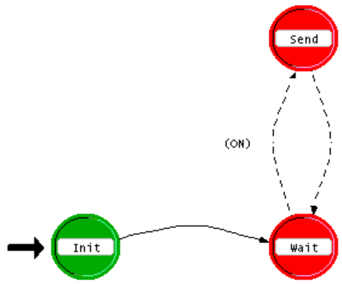

Fig. 8. ON/OFF OPNET traffic source model used inside M-ES. This process model generates packets in "send" state and rests in the "wait" state. Adjustment of the traffic burstiness is achieved by modifying the duration of these two states (ON/OFF time).

In this model, three parameters are essential in determining the level of burstiness of the generated traffic: the mean duration of the ON state, the mean duration of the OFF state, and the number of frames sent out during one ON period. In our simulation, durations of the ON-period and the OFF-period are exponential with means *a* and *b*, respectively. Based on the measurements, in our ON/OFF traffic model the packet size is fixed to 127 bytes.

3. Simulation results

In this section, we describe simulation experiments that demonstrate the practical significance of self-similarity in the queueing performance of a CDPD network. We also show that the use of traditional queueing approximations to select CDPD network operating parameters may lead to overestimating network performance.

In the M-ES node model in our simulations, we implement a queueing system with the following characteristics: first-in-first-out (FIFO), infinite buffer size, and arrivals that can be taken either from a genuine CDPD network traffic trace (trace-driven simulation), or from an ideal packet generator built in OPNET. The input traces consist of the measured inter-arrival times and packet sizes. The underlying assumption in engineering practice, also used in our research work, is that the traffic environment is stationary over a range of time scales. While this assumption is not always satisfied in practice, it appears to be a reasonable hypothesis for the traces we have used. In our simulation experiments, we also used input traces from bursty ON/OFF traffic source models, and from an exponentially distributed inter-arrival time process (Poisson arrivals). All three traffic sources (actual trace, traces generated by ON/OFF models, and Poisson arrival traffic) used in our study have the same mean, and, thus produce comparable traffic loads to the network. Therefore, we were able to compare the queueing performance of the CDPD network with various input traffic traces.

Fig. 9 shows the queueing performance of the simulated network with different input traffic types. As a function of the network bandwidth utilization, we plot the average delays for the actual traffic data (graph A), for the traffic trace generated by our ON/OFF source (graph B), and for a Poisson source (graph C). The difference between graphs A and C is evident. Comparing the distance between graphs A, B, and C, we conclude that the queueing performance of the traffic generated by an ON/OFF source is closer to the network performance observed with collected traffic data. This is to be expected, since ON/OFF sources reflect the bursty nature of the genuine network traffic better than Poisson sources.

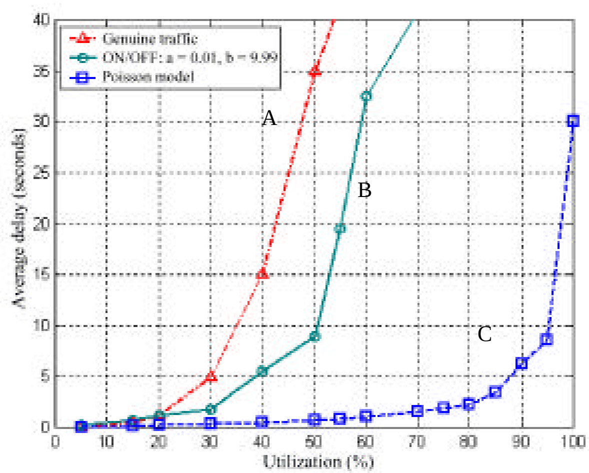

Fig. 9. Average delay vs. utilization plots for genuine traffic trace (graph A), traffic generated by ON/OFF model (graph B), and traffic generated by the traditional Poisson model (graph C).

4. Concluding remarks

In this paper, we used trace-driven simulation experiments to demonstrate that long-range dependence is an important traffic characteristic, and, if ignored, typically results in overly optimistic performance predictions and inadequate network resource allocations. As can be seen from our simulation results, the delay performance obtained with the genuine traffic trace is different from the performance predicted by Poisson arrival processes. In the case of moderate and high network utilizations, short-range dependent traffic source models (Poisson arrivals) underestimate queueing delays. The OPNET CDPD model, named "cdpd", has been deposited into the OPNET Contributed Model Depot [11].

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