MOBILE NETWORK TRAFFIC MODELING

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Approval of the Graduate School of Natural and Applied Sciences.

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ABSTRACT

MOBILE NETWORKS TRAFFIC MODELING

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The aim of this thesis is to investigate the traffic patterns in the mobile data networks. In this work, a simple Cellular Digital Packet Data (CDPD) network was modeled in order to be used in simulations. For the purpose of using in the CDPD model, a synthetic bursty traffic model was produced and using different traffic patterns some performance investigations were made in CDPD network. During the whole work, OPNET simulation tool was used.

The CDPD network modeled by OPNET simulation tool was compared with a CDPD model described in the literature and the differences were shown. The new model has some new features: 1) Burst transmission of MAC blocks. 2) Exponential backoff. 3) New packet structures. 4) Frame segmentation and encapsulation into MAC layer frames.

Using OPNET, a traffic having higher level of burstiness was produced and applied to the CDPD network model. Under the bursty traffic, some CDPD performance parameters were collected and according to the collected results some suggestions were given.

Keywords: OPNET, Wireless Networks, Mobile Networks, Self Similar Traffic, CDPD Networks, Network Simulation, Bursty Traffic, Traffic Modeling, Synthetic Traffic, Performance Parameters.

ÖZ

MOBİL AĞLARDA TRAFİK MODELLEME

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Bu tezin amacı gezgin ağlardaki trafik özelliklerini araştırmaktır. Bu çalışmada öncelikle benzetimlerde kullanılmak üzere basit bir Hücresel Sayısal Paket Veri (CDPD) ağ modellenmiştir. CDPD ağında kullanılmak üzere patlamalı yapay trafik üretilmiş ve değişik özellikte trafikler uygulanarak CDPD ağında başarım incelemeleri yapılmıştır. Bu çalışma boyunca OPNET benzetim aracı kullanılmıştır.

OPNET benzetim aracı yardımıyla modellenen CDPD ağı ile yazında yer alan bir modelleme çalışması karşılaştırılmış ve aralarındaki farklar ortaya konulmuştur. Yeni model birkaç farklı özellik sunmaktadır: 1) MAC bloklarının yığın halinde gönderilmesi. 2) Üssel geri çekilim. 3) Yeni paket yapıları. 4) Çerçeve segmentasyonu ve MAC seviyesi çerçevesine çevirme.

OPNET aracılığı ile daha patlamalı trafikler üretilmiş ve CDPD ağ modeline uygulanmıştır. Bu çalışma sonucunda patlamalı trafik altında bazı CDPD başarım parametreleri hesaplanmış ve bu sonuçlara göre patlamalı trafik altında CDPD ağında alınması gereken önlemler belirtilmiştir.

Anahtar Kelimeler: OPNET, Kablosuz Ağlar, Mobil Ağlar, Kendine Benzeyen Trafik, CDPD Ağları, Ağ Simülasyonu, Patlamalı Trafik, Trafik Modellemesi, Yapay Trafik, Başarım Parametreleri.

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1xRTT	1x Radio Transmission Technology
AMPS	Analog Mobile Phone System
AR	Auto-Regressive
ARIMA	Auto-Regressive Integrated Moving Average
BER	Bir Error Rate
CDPD	Cellular Digital Packet Data
CLNP	Connectionless Network Protocol
CSMA/CA	Carrier Sense Multiple Access / Collision Avoidance
DSMA/CD	Carrier Sense Multiple Access / Collision Avoidance
FARIMA	Fractional ARIMA
FBm	Fractional Brownian Motion
FEC	Forward Error Correction
F-ES	Fixed End System
FGn	Fractional Gaussian Noise
FIFO	First In First Out
FSM	Finite State Machine
GMSK	Gaussian Minimum Shift Keying
GPRS	General Packet Radio Service
HSCSD	High Speed Circuit Switched Data
IS	Intermediate System
LMCS	Local Multipoint Communication Service
LMDS	Local Multipoint Distribution Service
MAC	Medium Access Control
MBT	More Bursty Traffic
MDBS	Mobil Date Base Station
MDIS	Mobile Data Intermediate System
MDLP	Mobile Data Link Protocol
M-ES	Mobile End System
MFA	Multifractal Analysis
MHF	Mobile Home Function
MMDS	Multichannel Multipoint Distribution Service

MSF	Mobile Serving Function
MWM	Multifractal Wavelet Model
OPNET	Optimum Network
OSI	Open Systems Interconnect
PCS	Personal Communications Service
PDC	Packet Data Cellular
RS	Reed Solomon
SIM	Subscriber Identity Module
SNDCP	Sub-Network-Dependent Convergence Protocol
SNR	Signal To Noise Ratio
SRD	Short Range Dependent
VPN	Virtual Private Networks
Wi-Fi	Wireless Fidelity

CHAPTER 1

INTRODUCTION

1.1. Brief Introduction to Wireless Networks

The followings are the communication needs for which wireless networks have been created:

- Communications service (PCS)
- Wireless local area networks
- Local multipoint communication systems (LMCS)
- Cellular, mobile communications
- Satellite communications and,
- Cellular digital packet data (CDPD).

We can present some important features, advantages and disadvantages of wireless networks in the following titles: Cost, Flexibility, Roaming, Extended Coverage, Standards, Management, Interference, Performance, Security [22].

Wireless data networks exist in such number and variety as to be difficult to categorize and compare [22].

Here are some examples of wireless networks :

- CDPD (Cellular Digital Packet Data)
- HSCSD (High Speed Circuit Switched Data)

- PDC-P (Packet Data Cellular)
- GPRS (General Packet Radio Service)
- 1xRTT (1x Radio Transmission Technology)
- Bluetooth
- IrDA
- LMDS (Local Multipoint Distribution Service)
- MMDS (Multichannel Multipoint Distribution Service)
- 802.11 (Wi-Fi).

Bluetooth is used for connection of small devices over short distances [22].

1.2. Cellular Digital Packet Data (CDPD) Networks

The main characteristics of Cellular Digital Packet Data are as follows [15]:

- Uses the AMPS cellular telephone infrastructure [15].
- Full duplex channel structure with a pair of unidirectional channels
- Channel capacity:19.2Kbps
- Reed-Solomon (63,47) as error-correcting code currently
- 2 channels: “Forward channel” for base station transmission, “Reverse channel” for mobile hosts access
- MAC protocol for the mobiles is Digital Carrier Sense Multiple Access with Collision Detection (DSMA/CD).

The details of CDPD network is in the CHAPTER 3.

1.3. Performance Problems of Wireless Mobile Networks and Introduction to Traffic Modeling

The different types of performance problems in wireless networks were encountered in the past. Some of them were solved while the others are still subject to a solution.

Having too many wireless devices within close proximity is one of the most common problem [24].

Poor antenna connections is another wireless network problem to be solved [24].

[24] states that “fust” is the most common performance-related problem on big, expensive, outdoor networks for Wi-Fi (Wireless Fidelity) networks. Fust forms poor signal strength.

Access point oversubscription is another common problem regarding Wi-Fi networks. Having high number of wireless communication is impractical [24].

As stated in [24], multipath, which is occurred when a signal bounces off of nearby objects and arrives at the receiver at different times, is an important problematic subject to be dealt with.

Wireless networks share their airspace with a number of other devices and technologies, which may influence overall performance.

Network topology changes are also big problems for wireless networks that must be handled properly for performance.

Capacity increase and coverage expansion are urgent need for wireless user currently because they need more functionality and features. Also as network performance and reliability become more critical to maintain, in order to meet this demand, wireless networks must be dynamic and operate at full efficiency.

In addition to problems of wireless networking, mobility brings some other problematic networking issues. [18] states that it is expected to efficiently send and receive communications from wherever you are, once you have accessed the network. This is called mobility management or location management. The mobile is essentially nowhere if it is powered down or out of range of the system; this is an important situation to consider in any mobile system [18].

For cellular mobile networks, handover, which is seamless service to active users while data transfer is in progress, is important issue to deal with.

[18] also states that rapid convergence of router protocols (i.e., adaptation of the routing information database to changing network state is another problematic subject of mobility. Routing protocols must converge more quickly than network topology changes occur or the internetwork operation will break down from the congestion caused by misdirected packets.

As stated in [26], in general, we can say that modeling the traffic can be very difficult. It is hard to measure and collect data that characterize the network traffic on users' side. Also, generalization of traffic characteristics of a specific network to other networks is not possible. As a result we need to study as many different data sets as possible [26].

[20] states that as a traditional traffic model, Poisson processes are often used when modeling network traffic, packet and connection arrivals because such processes have attractive theoretical properties. According to [20], However, a number of studies have shown that the distribution of packet interarrivals clearly

differs from exponential for a variety of network types. This is also valid for wireless networks like CDPD. LAN traffic is much better modeled using statistically self-similar processes which have much different theoretical behavior than Poisson processes. What is absent in Poisson and the other traditional traffic is the long-range dependency of actual traffic [20].

1.4. Objective and Scope of the Thesis

The objective of this thesis is to investigate the impact of traffic patterns on CDPD wireless data networks especially for queue performance.

First of all a CDPD network model will be generated using OPNET simulation tool. The model will be based on the CDPD standard specifications. This model will form the infrastructure of the whole thesis work. This model will be compared to a prior CDPD model [21], which forms basis for our model. Some parts of CDPD Model [21] are used without any change. We have trace traffic data collected from Telus Mobility CDPD network [25]. A synthetic traffic model will be produced in order to model the trace traffic and validated. For the investigations on buffer performance of CDPD M-ES node, traffic which has higher level of burstiness, will be modeled and applied to our CDPD model.

The thesis consists of five chapters. A brief introduction to wireless mobile networks and CDPD networks, a brief overview of performance problems on wireless networks, and a brief introduction of traffic modeling issues are given in the first chapter. Chapter 2 presents a literature survey on traffic types and traffic characteristics. In Chapter 3, first a CDPD overview is presented. Then OPNET model of CDPD wireless network is described. As a final work in this chapter, a comparison between our model and the prior CDPD model is presented. Chapter 4 consists of a synthetic traffic modeling of the trace traffic in OPNET and investigation of buffer performance issues of CDPD M-ES node under bursty traffic modeled in OPNET. Finally, evaluation of the results of the simulations and important conclusions derived from the study are presented in Chapter 5.

CHAPTER 2

LITERATURE SURVEY ON TRAFFIC TYPES AND TRAFFIC CHARACTERISTICS

2.1. Self-Similar, Mono-Fractal Traffic

[25] states that latest traffic studies have revealed a new phenomenon called self-similarity. The characteristic of packet generation time, i.e. packet interarrival time, results in self-similarity. "Roughly, traffic carrying Self-Similarities looks statistically the same over a wide range of time scales and is related to Long Range Dependence (LRD), i.e. the existence of correlation over a broad range of time scales" [25].

We can present here a brief definition of self-similarity for stochastic processes according to [25]. Assume X_k (k =1, 2...) to be a wide-sense stationary process with mean $E(X_k) = \bar{X}$ and autocorrelation function r (i). Next, consider the processes:

$$X_k^{(m)} \; (m = 1, 2, \ldots)$$

that are constructed from X_k *by* averaging over non-overlapping blocks of size m as

$$X_k^{(m)} = \left(\sum_{(i=0)}^{(m-1)} X_{km+1} \right) / m$$

The process $X_k^{(m)}$ is also wide-sense stationary, with mean $\bar{X}$ and autocorrelation function $r^{(m)}(i)$. The process X_k is called (exactly) second-order self- similar if $r^{(m)}(i) = r(i)$ for $i \geq 0$, and (asymptotically) second-order self-similar if $r^{(m)}(i) = r(i)$, for $m \rightarrow \infty$. As a result, self-similar process has slowly decaying variances and slowly decaying autocorrelation function.

Such a process differs from the traffic generated by traditional Poisson models used for modeling voice traffic that has exponentially fast decaying autocorrelation function [25].

We can determine the level of self-similarity with the aid of Hurst parameter, H. Self-similarity is implied by $0.5 < H < 1$, [25]. In [4], three basic approaches for estimating H are revealed:

- Analysis of the variances of the aggregated process
- Analysis of the rescaled range (R/S) statistic for different block sizes
- A **Whittle Estimator**

[4] states that while first two graphical estimation methods are useful to estimate H, they may be inadequate for large H. However **Whittle Estimator** provides a confidence interval. On the other hand, a different approach for estimating H called Wavelet-Based Estimation dominates all of the above three methods. In Wavelet-Based approach, estimation is made in wavelet domain. In [2], some other approaches for estimating H are revealed in addition to above four; Periodogram method, and Correlogram plot.

In [2], some Self-Similar stochastic processes in modeling Self-Similar traffic are presented:

- *Fractional Brownian Motion (FBm)*: is a zero mean, gaussian process
- *Fractional Gaussian Noise (FGn)*: is known as increments of FBm.

- *FARIMA (Fractional ARIMA models) Models*; are built on classical ARIMA models.
- *Wavelets:* Wavelets offer a means of transforming the original Self-Similar process into a new process with much less Self-Similar behavior.
- *On/Off Processes*: A large number of superimposed heavy tailed On/Off processes can yield Self-Similar traffic as well.
- *Poisson-Zeta Process*: is a discrete time On/Off process.
- *Self-Similarity Through Aggregation*: a more sophisticated process, yielding Self-Similar traffic through *aggregation* exists.
- *The M/G/∞ Model*: is capable of constructing asymptotically Self-Similar traffic.
- *Superimposing AR (1) processes*: a typical application is mixing of two AR (1) processes to generate ATM traffic.

Self-similar traffic can have a detrimental impact on the network performance [4]. [12] states that the queuing performance gets worse with self-similar traffic. Buffers needed at switches and multiplexers must be bigger than those predicted by traditional queuing analysis and simulations [4].

The work done in [25] is a good example about the effect of self-similar traffic on queuing performance. They used trace-driven simulations with genuine traffic data collected from the Telus Mobility CDPD network. The trace traffic was applied the CDPD network model designed in OPNET. The preliminary results from the simulations suggest that the collected wireless data traffic tends to have a self-similar behavior, and that it is statistically different from traffic generated by traditional traffic models. According to [25], genuine traffic traces also cause higher buffer overflow probabilities than the conventional traffic models. This may require lower wireless link utilizations in order to avoid undesired loss rates. Nevertheless, the trace was too short (20 minutes long) to warrant a more definite conclusion.

2.2. Multi-Fractal Traffic

Unlike MonoFractal traffic, MultiFractal traffic takes into account the changing local scaling behavior over time [2]. In MultiFractal spectrum, Hölder continuity (i.e. strength of growth), Ht, varies erratically with time [3]. In [3], the estimation of the multifractal spectrum from a finite-length, discrete time data sequence is presented. This estimation is done using wavelet-based approach with a given N samples of a single realization FBm process. Also, [2] mentions the wavelet-based method for estimating MultiFractal property.

In [3], a wavelet-domain model of a positive, stationary, and LRD signal is developed. For this purpose, a simple Haar wavelet construction is used. This models poses multifractal behavior. So, it is called Multifractal Wavelet Model (MWM). [3] states and shows that MWM, like FGn models, the MWM can properly model power spectrum, and hence the LRD, of a set of positive training data if the variances of the multipliers are chosen appropriately. However, the MWM can also match higher-order statistics due to its multiplicative construction. Also, [3] introduces a multifractal spectra (measures of spikiness) and then shows that FBm has a degenerate multifractal structure. The connection between LRD and Multifractal Analysis (MFA) and multifractal spectrum of the MWM are unraveled. *T(q)* ,called partition function. According to its characteristics, degree of multifractal behavior of a (traffic) model is revealed.

2.3. Long Range Dependency

[10] describes the definition of LRD as the slow power-law decrease of the autocorrelation function of a process with Hurst parameter, H, >0.5, corresponding the divergence of the autocorrelation sum. In other words, processes with LRD are characterized by an autocorrelation function that decays hyperbolically in the lag [1]. As examples, Ethernet data traffic and VBR video traffic reveal LRD characteristics. FGn (Fractional Gaussian Noise) and

FARIMA (fractional ARIMA) models exhibit Long Range Dependency characteristics. [10] states the close relation of LRD to the properties of scale invariance, self-similarity and hence fractals, and is therefore often related to statistically self-similar processes such as the Fractional Brownian Motion (FBm).

It is known that queuing performance get worse with self-similar traffic whose Hurst parameter is between 0.5 and 1, i.e., LRD traffic. [12] states that it is important for the appropriate buffer design of routers and switches to predict the queuing behavior under self-similar traffic with LRD.

Other than the traffic models of the LRD traffic mentioned above, modeling the LRD traffic in wavelet domain is also possible bringing simplicity and accuracy to modeling. [7] shows the correlation structure of wavelet coefficients of LRD processes. Also, [7] states that simple models of LRD traffic which are insufficient in the time domain may be quite accurate in the wavelet domain. In [7], performance of a specific wavelet model (independent wavelet model) on LRD is discussed.

[6] develops a wavelet-domain model for a positive, stationary, LRD process. [10] shows a wavelet-based tool for the analysis of Long Range Dependence and a related semiparametric estimator of the Hurst parameter. A wavelet-based H estimator is presented in [10]. Some comparisons are done with the other estimators. Wavelet based estimator brings advantages. Estimation is done more properly than the others (Whittle estimator,...) do. As for the computational issues, it also dominates the others with a computational complexity O(n). As a result, the wavelet-based H estimator leads to a simple, low cost, scalable algorithm, [10].

In [10], a wavelet-based analysis of Ethernet data is done, which reveals the evidence LRD phenomenon in Ethernet data traffic. In this work, results are described based on a trace, *pAug*, which was taken at *Bellcore* in the late 1980's and early 1990's.

2.4. Short Range Dependence

According to [9], we can describe the Short Range Dependent traffic as follows: the decay rate of the corresponding auto-covariance function is either exponential or polynomial (of order greater than one) so that the auto-covariance is non-summable. Auto-Regressive (AR) processes and Auto-Regressive-Moving-Average (ARMA) processes are the most known examples of short-range dependent random processes [7].

[7] analyses the correlation structure of wavelet coefficients of SRD processes, and shows that correlation of wavelet coefficients decays exponentially. Wavelet transform significantly reduces the temporal dependence so that a complicated mixture of short–, and long–range dependence in the time domain may be sufficiently modeled by a "short-range" dependent process in the wavelet domain. In [7], performance of wavelet models in modeling short-range dependence is discussed. For this purpose, an AR (1) processes with AR parameter 0.9 is chosen to evaluate the performance. [7] plots the sample autocorrelation and buffer response for AR and wavelet correlation models; independent wavelet model, markov wavelet model. Independent wavelet model, which neglect all the dependence in the wavelet domain, performs reasonably well. Markov wavelet models, which capture more correlation among wavelet coefficients, do improve performance.

2.5. Homogeneous Traffic

In this type of traffic, there is only one type of source, which generates traffic to the network. In [13], traffic behavior of a single GPRS user is modeled for FTP, WAP, E-MAIL, and WWW applications. For these applications, two types of processes are used in modeling single user behavior:

- *ON/OF-process* where the ON-state stands for the active phase, meaning that user is using the application, OF-state is the idle period.
- *Renewal-process;* When ON-state is short compared to the ON/OF cycle length; a renewal process is used to describe the traffic.

2.6. Discussion

We will focus on the self-similar traffic described in [25] in the following chapters of the thesis. Most network traffic measurements have been performed on wired networks and thus self-similarity in wireless data networks are subject to detailed research. Self-similarity on traffic pattern requires close attention because it requires larger buffers in the network's elements than traffic generated by traditional models, [25]. In the thesis work, we tried to reveal the behaviour of wireless data network under self-similar traffic, i.e. bursty traffic.

In the analyses of wireless data network behaviour under self-similar traffic, we used Poisson, exponential and pareto distributions in order to generate the required traffic in this study. ON-OFF traffic model was used with appropriate traffic generation parameters settings in order to generate self-similar traffic patterns. Among the other mono-fractal traffic models such as Wavelets, FARIMA and the others, ON-OFF was used because it is easy to implement and to configure in OPNET. Poisson traffic model was used for comparison purposes. In addition, an available trace data traffic pattern was used in our work for validation and comparison purposes.

CHAPTER 3

CDPD OVERVIEW AND OPNET MODELING OF CDPD NETWORK

In this chapter, first we give a description of CDPD (Cellular Digital Packet Network), and then OPNET model of CDPD network is introduced. Finally, some performance comparisons are made between our OPNET model and the model by [21].

3.1. CDPD OVERVIEW

According to [25], Cellular Digital Packet Data (CDPD) is a wireless packet switched data technology. It overlays on analog cellular telephone system. As stated in [25], the Specification includes the following major areas [25]:

1. CDPD communications architecture
2. Key interfaces
3. Protocol stacks
4. Radio resource control
5. Mobility management
6. Accounting management
7. Support services, and
8. Network management.

In the following sub-sections, detailed discussions about the CDPD architecture, protocol stacks, and the Airlink Interface are available.

3.1.1. CDPD communication architecture

The CDPD protocol stack is based on the OSI Basic Reference Model and it contains only the lower three OSI layers. Fig. 3.1 presents the network elements as defined in CDPD [15].

The CDPD Network is comprised of five logical components: Mobile-End System (M-ES), Mobile Data Base Station (MDBS), Mobile Data Intermediate System (MD-IS), Intermediate System (IS), and Fixed-End System (F-ES). The purpose of the CDPD network is to allow data transmission between Mobile End Systems (M-ES) and Fixed End Systems (F-ES).

These components communicate with one another via three logical interfaces: Air interface, External Interface and Internal Interface.

3.1.1.1. Mobile End System (M-ES)

Network end users connect to CDPD network via Mobile End System (MES), which is an independent network component [25]. We can describe it as a form of a specialized modem. MES communicates through the airlink with other network components. On the other hand, the CDPD network, guaranties the packet delivery to the MES. Mobile end systems use protocols defined up to OSI layer 3, which makes MES capable of having an IP address.

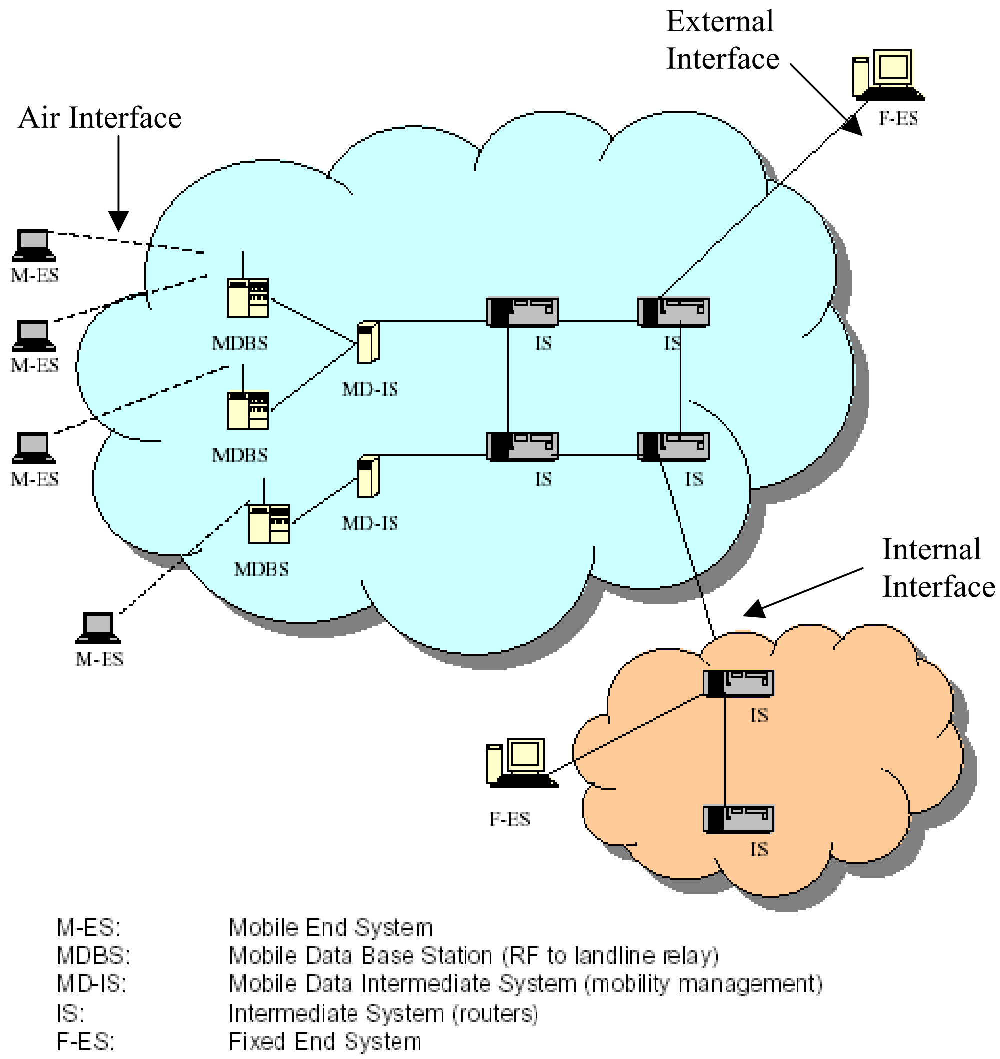


Figure 3. 1 CDPD Network Architecture [25]

3.1.1.2. Mobile Data Base Station (MDBS)

[25] states that Mobile Data Base Station (MDBS) performs two functions. First, it manages the activities in the reverse channel. In a CDPD network much like the Ethernet, an RF channel is shared between several M-ES. In this case MDBS is an arbitrator in CDPD MAC scheme, also known as digital sense multiple access. It relays data packets to mobile data intermediate system. Second, MDBS may be seen as a bridge between M-ES and CDPD network. It

performs modulation of data bit stream at one end and demodulation of RF signal into data bit stream at the other end. MDBS uses Gaussian Filtered Minimum Shift Keying (GMSK) modulation scheme at a bit rate of 19.2 kilobits per second [25].

3.1.1.3. Intermediate System (IS)

As stated in [27], Intermediate System is a physical device, which is responsible for routing and forwarding packets either using a Connectionless Network Protocol (CLNP) or Internet Protocol (IP). Other functions of IS are route calculation, fragmentation and congestion mitigation. In other words, IS is a multiprotocol router [27].

3.1.1.4. Mobile Data Intermediate System (MDIS)

Based on the M-ES location, MDIS is responsible for routing functions. It has two different routing functions: Mobile Home Function (MHF) and Mobile Serving Function (MSF), which provide network services to M-ES regardless of its location [27].

3.1.1.5. Fixed End System (F-ES)

FES can be seen as any system that is not mobile. It may be external or internal to the CDPD networks. The external F-ES may be located on any network anywhere in the world connected over a landline [27].

3.1.2. Protocol stacks and Airlink Interface

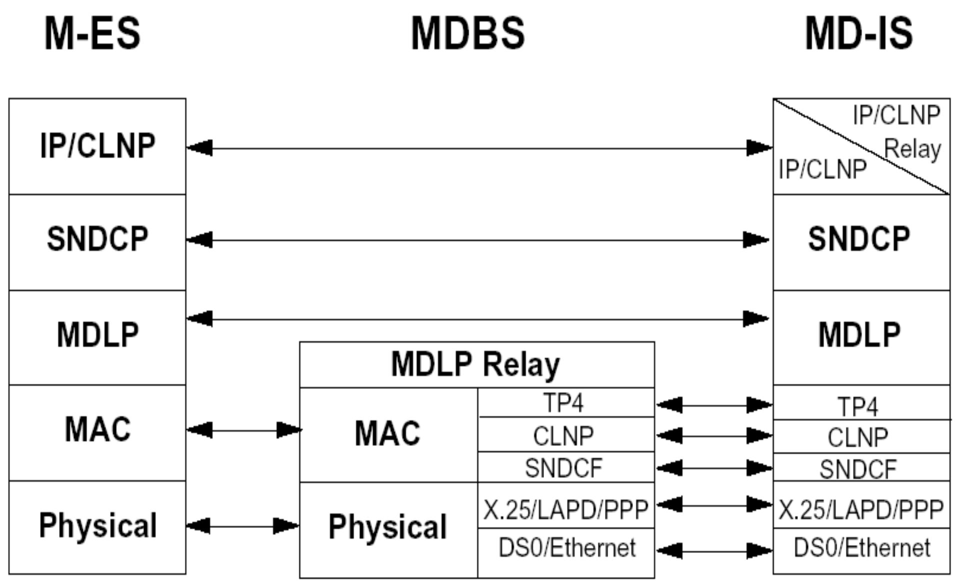


Figure 3. 2 Airlink Protocols [25]

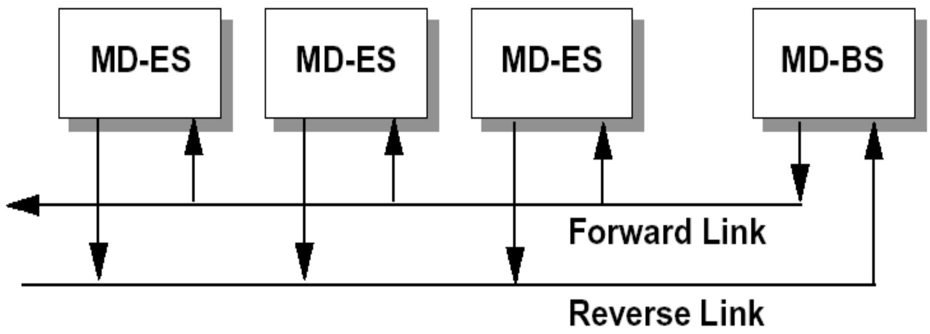
Fig 3.2 shows that transmission of network layer protocol data units (NPDU's) or packets between the M-ES and the MDIS are realized across a mobile data link connection using the Mobile Data Link Protocol (MDLP) [25]. Similar to [25], in our simulation, we focus on the communication between the M-ES and MDBS, which use the MAC and physical protocols.

3.1.3. Medium access control layer

According to [25], frame transfer between the M-ES and the MDBS is achieved by the medium access control (MAC) layer. Data encapsulation, medium access management on the reverse channel, and channel stream timing and synchronization are the basic functions of this layer. Data encapsulation includes the following tasks: frame boundary delimitation, data transparency, frame synchronization, and error detection and correction (Reed-Solomon encoding). Medium access management algorithm is slotted nonpersistent Digital

Sense Multiple Access with Collision Detection (DSMA/CD) scheme. This management algorithm enables collision detection using the decode failure flag. Also, it allows M-ES's to synchronize to a master microslot clock before starting a transmission [25].

Fig 3.3 shows the communication links between M-ES and MDBS.



Forward link: scheduled by BS, signals channel idle/busy
Reverse link: contention access with back-off

Figure 3. 3 Channels between M-ES and MD-BS

3.1.4. Digital sense multiple access with collision detection

In order to access the medium before starting transmission M-ES uses Digital Sense Multiple Access (DSMA). DSMA is quite similar to the standard Ethernet access protocol (Carrier Sense Multiple Access, or CSMA). The MDBS provides service when contention for the frequency resource of reverse channel is attempted simultaneously by multiple M-ES's. Related to this scheme, there are two information flags available in the communication network. One is Channel Busy/Idle Status flag, which is used to check the channel availability. So, this flag serves as collision avoidance. The other is Block Decode Status, which is used to check collision occurrence after transmission. This flag enables collision detection [25].

3.2. OPNET MODEL OF CDPD NETWORK

In this section, we present a detailed description of the network model we used to investigate the impact of self-similarity on CDPD network performance. This model is based on the prior CDPD model [21]. In this work, OPNET Modeler was used for modeling and simulation of CDPD networks. Its object-oriented modeling approach and graphical editors mirror the structure of actual networks and network components. According to [25], BCTel's mobile data network is a typical commercial CDPD network, where base stations are located on top of high-rise buildings, and the users are mostly police and fire departments. The trace traffic used for our analysis was collected on the reverse channel in a CDPD cell [25].

Three layers form the hierarchical structure of an OPNET model:

- OPNET Network Layer Model defines the position and interconnection of communicating entities, or nodes.
- OPNET Node Model is used for describing connection of processes, protocols, and subsystems.
- OPNET Process Model is used for functionality of each node process.

Fig. 3.4 presents the each layer available in OPNET modeling. Fig. 3.5 displays the phases of the modeling and simulation cycle of OPNET [25].

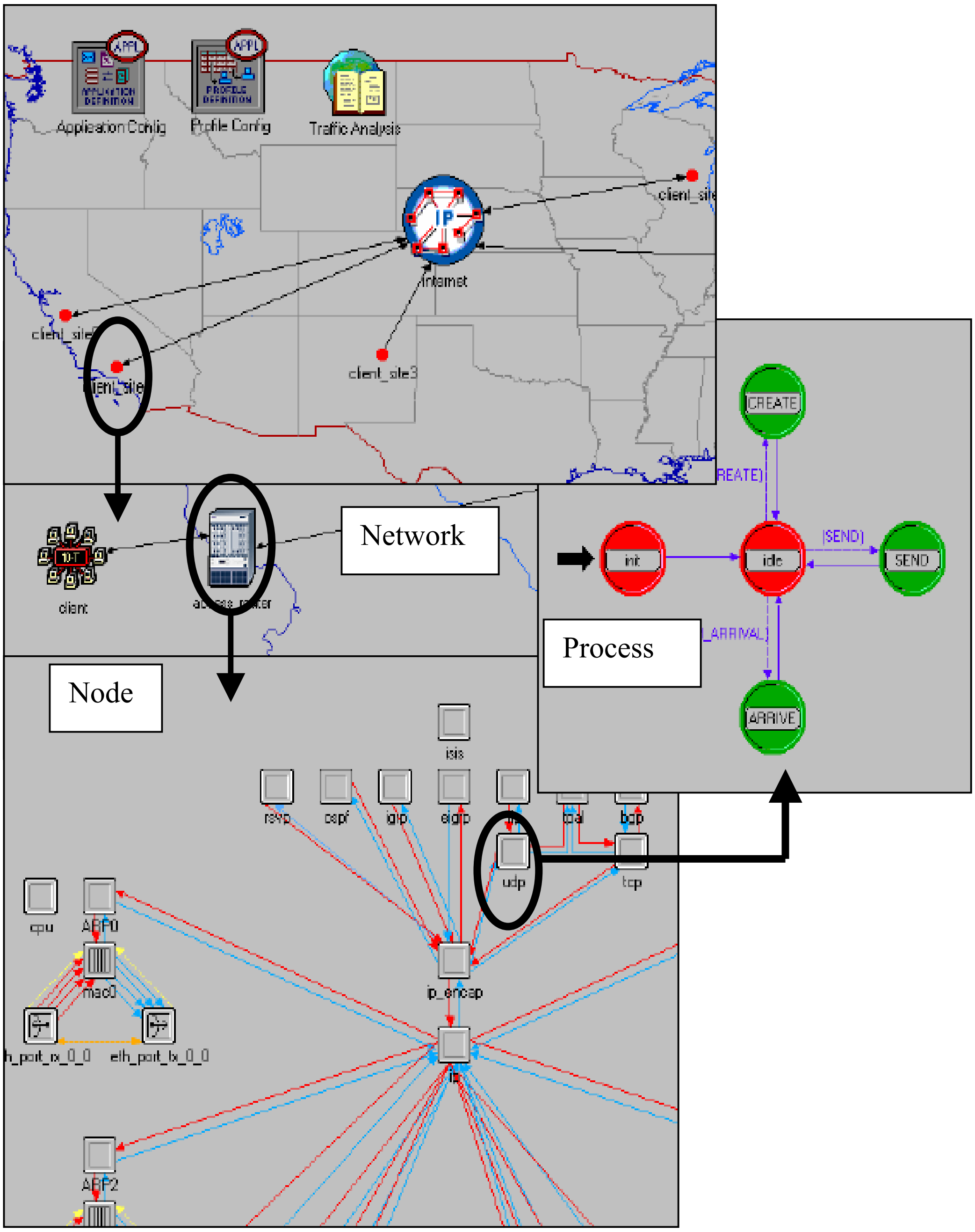


Figure 3. 4 Hierarchical Structure of an OPNET Model

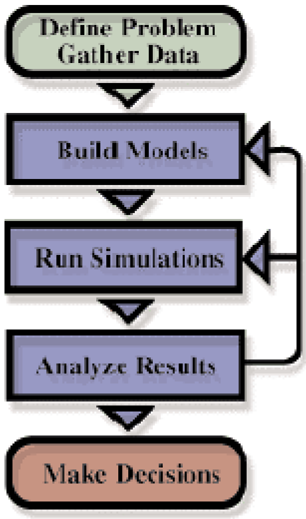


Figure 3. 5 Opnet Modeling and Simulation Cycle [25]

The OPNET network model of our CDPD network is shown in Fig 3.6.

3.2.1. OPNET CDPD Network Model

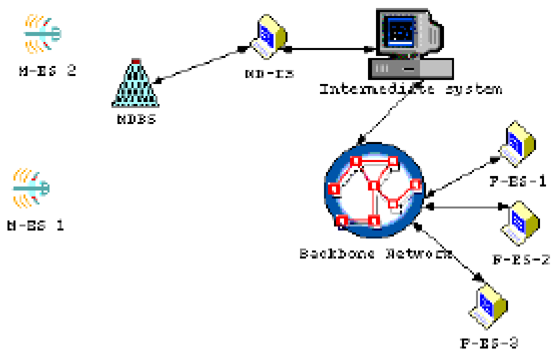


Figure 3. 6 CDPD Network Model [25]

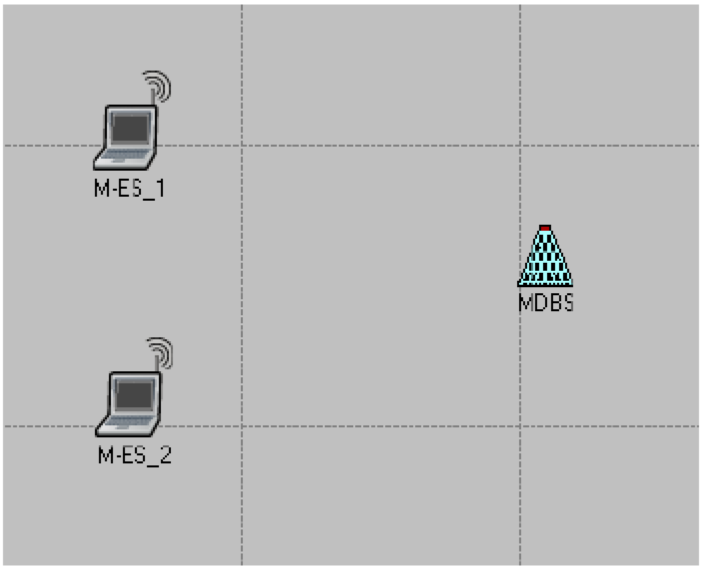


Figure 3. 7 Network Model For The Airlink Interface

The two M-ESs send packets to the MDBS in the reverse channel at a center frequency of 825 MHz. They receive packets from the MDBS in the forward channel at a center frequency of 870 MHz.

In the network model of the Airlink Interface shown in Fig. 3.7, the M-ES nodes compete for the bandwidth (825 MHz ~ 825 MHz + 30 KHz). Each M-ES generates data packets according to the traffic pattern defined (e.g. genuine trace collected from the operational CDPD network, Poisson, ON-OFF…). Other traditional traffic models are also available from the OPNET libraries, such as Poisson and Gaussian models. The MDBS behaves like an Ethernet hub [25].

3.2.2. OPNET Node Models

The OPNET M-ES node model is shown in Fig. 3.8. M-ES node contains Traffic Sink and source, M-ES MAC, Channel Monitor, a radio receiver&transmitter pair.

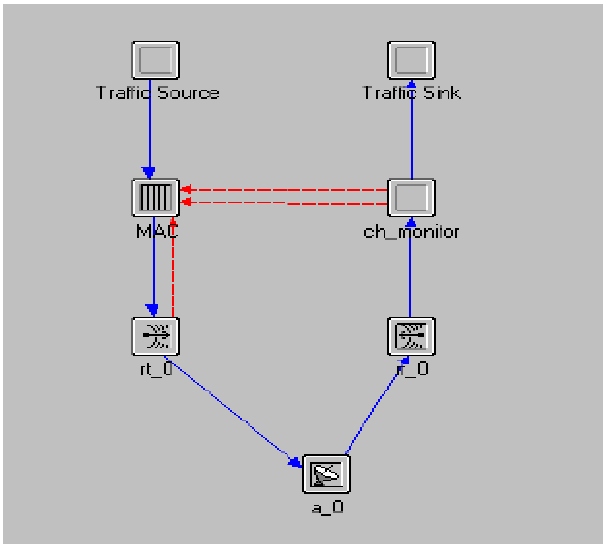


Figure 3. 8 OPNET M-ES (Mobile End Station) Node Model

According to the CDPD standards [15], the center frequency of the receiver (forward channel) is adjusted to 870 MHz, with a bandwidth of 30 KHz. The center frequency of the transmitter (reverse channel) is adjusted to 825 MHz, with a bandwidth of 30 KHz [25].

The MAC processor implements the digital sense multiple access (DSMA) algorithm. It gets 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 off for a random time period and will try to retransmit again.

The traffic source generates packets according to traffic profile set. In this work, genuine traffic trace, Poisson, and ON-OFF traffic models were used. The traffic sink destroys the packets coming from MDBS node.

The OPNET MDBS node model that has been developed within the scope of this study is shown in Fig. 3.9. It receives packets from the M-ES via a radio receiver operating at a center frequency of 825 MHz, and transmits packets via a radio transmitter at a center frequency of 870 MHz.

In actual CDPD network, this node has the interface between the wireless part and the wired part of a CDPD network. In the process called MAC, the DSMA/CA algorithm is modeled. It sends the *busy/idle* and *decodes status* flags to the listening M-ESs. MDBS sends the control packets containing the status of the reverse channel to the forward channel. This control packet is repeated at every second.

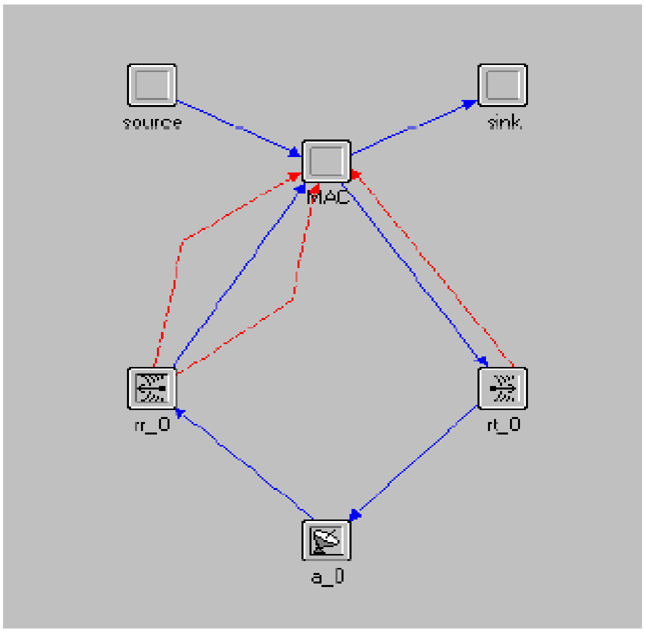


Figure 3. 9 OPNET MDBS (Mobile Data Base Station) Node Model

3.2.3.OPNET Process Models

3.2.3.1. M-ES MAC Process Model

This process model (Fig. 3.10) implements the DSMA/CA algorithm. It gets packets from M-ES source and encapsulates the packets into MAC frames, and to transmitted these frames through the reverse channel to the MDBS. The FIFO scheduling scheme is used in this process model.

In *idle* state, process waits for a new packet generation. After packet generation, process moves to the *bis_check* state where it checks the status of the reverse channel. According to the status of the reverse channel, there are two possible next state to which process enters. If the channel is IDLE, then next state is *send* state. In this state, a block of data stream is transmitted. If the medium is BUSY, then process moves to the *defer* state. In *defer* state, we wait during a random time before checking the channel status again according to an exponential backoff algorithm. MAX_TX_ATTEMPTS is the limit for number of checks. If this limit is exceeded then process moves to the *block* state, in which transmission is aborted. If the channel is sensed as IDLE before the limit is exceeded, then *send* state becomes active. After transmission of data stream, process moves to the *decode_wait* state where it waits for collision detection. During 7 microslots (21.875 ms), if no decode failure is received from MDBS then it means that the transmitted packet is received correctly and it is removed from the queue.

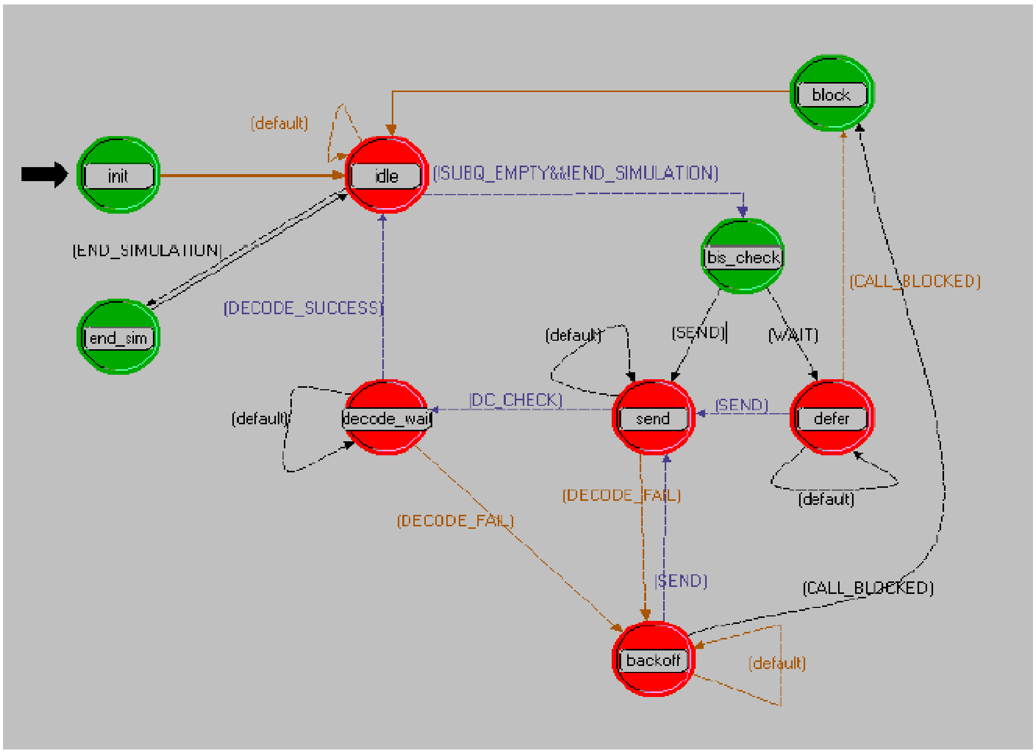


Figure 3. 10 CDPD M-ES MAC FSM

Detailed description of functions of each state, are given in TABLE 3.1.

Table 3. 1 CDPD M-ES MAC Process State Explanations [25]

Name	***Explanations***
init	This is the first state entered by the process model and the initial interrupt should be the **begin simulation interrupt**. State variables are initialized.
idle	In this state, process waits for a new packet generation.
bis_check	Channel status is checked.
defer	According to an exponential backoff algorithm, in this state process waits for a random time before checking the channel status again.
send	Process sends a block of data stream.
decode_wait	In this state, process waits for decode information from MDBS.
backoff	According to an exponential backoff algorithm, in this state process waits for a random time before checking the channel status again.
block	When the process moves to this state, current transmission is aborted.
end_sim	The simulation is completed. The resources are released.

Below table (TABLE 3.2) shows the default values of the configurable M-ES MAC parameters used during the simulations. The values were suggested by the CDPD Forum and can be found in [15].

Table 3. 2 CDPD M-ES MAC Configurable Parameters [25].

Parameter	Default Value	Explanation
MIN_ENTRANCE_DELAY	35	The maximum amount of microslots (60 bit times = 3.125 milliseconds) that the M-ES will wait when attempting to re-access a channel for an initial burst.
MIN_COUNT	16	Due to decode failures, an M-ES will attempt to retransmit in no less than [2 (to the 4th power)]-1 microslots time intervals.
MAX_COUNT	256	Due to decode failures, an M-ES will attempt to retransmit in no more than [2 (to the 8th power)]-1 microslots time intervals.
MIN_IDLE_TIME	0	Time to wait before entering *idle* state after DECODE_SUCCESS event.
MAX_TX_ATTEMPTS	13	The number of times an M-ES will observe Busy/Idle flags in order to gain access to a CDPD channel before declaring the channel congested.

MAX_BLOCKS	64	The maximum amount of blocks in one continuous transmission burst.
MAX_BURST_SIZE	24192	The maximum number of bits in one transmission attempts that can be sent by M-ES

3.2.3.2. CDPD M-ES&MDBS Sink Process Model

This process model (Fig. 3.11) exist both in M-ES and MDBS node models. In M-ES, it waits for the forward channel MDBS packets from Channel Monitor process model and discards the packet. In MDBS, sink destroys the packet from M-ES nodes.

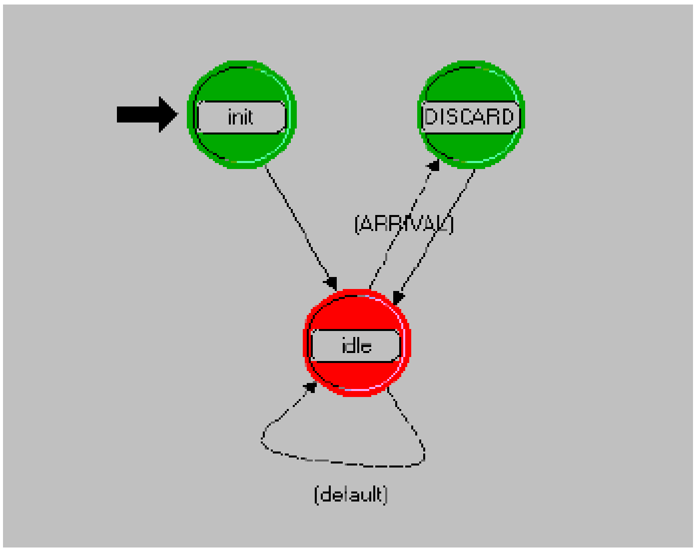


Figure 3. 11 CDPD M-ES&MDBS Sink FSM

3.2.3.3. CDPD M-ES Trace Generator Process Model

For this FSM, we used the ***cdpd_trc_gen*** process model (Fig 3.12) in [25]. To run a “trace driven” simulation, it is required to input measured CDPD network traffic trace into the network model. We have two data available in the trace data. First is the packet generation time and the other is packet size. In this state, self-interrupts are produced according to the packet generation times. When the related self-interrupt is produced, a new CDPD packet with the related size is generated and forwarded to the cdpd_mes_mac process [25].

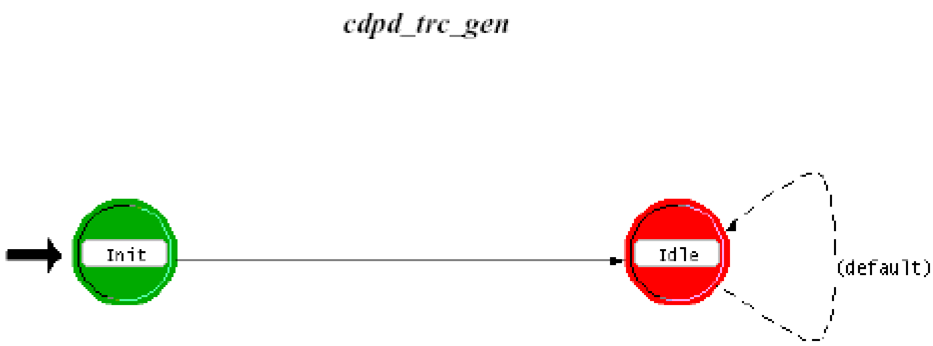


Figure 3. 12 FSM of cdpd_trc_gen [25]

Detailed description of functions of each state, are given in TABLE 3.3.

Table 3. 3 CDPD M-ES cdpd_trc_gen Process State Definitions [25].

Name	Explanations
Init	This is the first state entered by the process model and the initial interrupt should be a **begin simulation interrupt**.
Idle	In this state, when a self interrupt happens, the process model will generate a packet and schedule a self interrupt at the generation time of the next packet.

3.2.3.4. CDPD M-ES Channel Monitor Process Model

This process models (Fig 3.13) gets the MDBS control packet from forward channel and extracts the busy/idle and decode status flags from the packet. These flags are used by M-ES MAC process model by the aid of statistical wires between M-ES MAC and Channel Monitor process models.

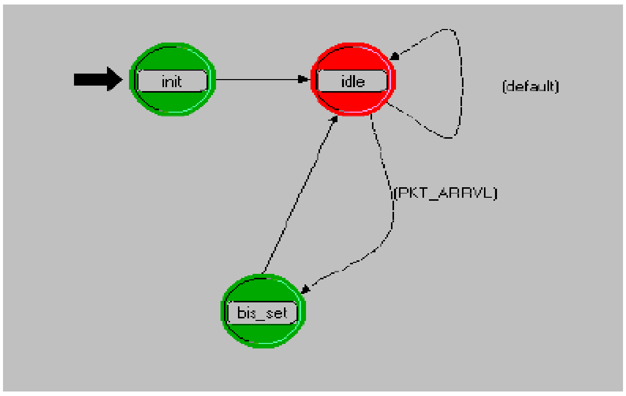


Figure 3. 13 CDPD M-ES Channel Monitor FSM

3.2.3.5. CDPD M-ES ON-OFF Process Model

The structure of the ON/OFF traffic source model is shown in Fig. 3.14. This model belongs to the prior CDPD model and is used without any change in this study. In order to determine the level of burstiness, there are three essential parameters used: Mean duration of the *ON* state, mean duration of the *OFF* state, and the number of frames sent out during one *ON* period [25].

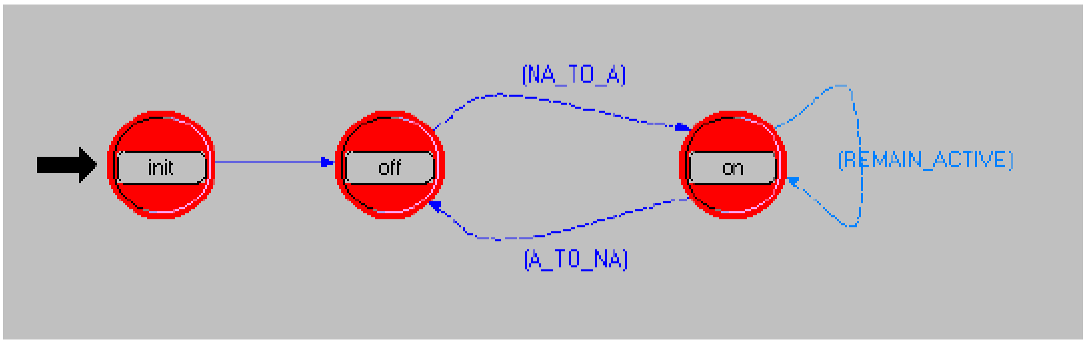


Figure 3. 14 CDPD M-ES ON-OFF FSM [25]

The relationship of the three parameters is shown in Fig. 3.15. Average duration of the ON- period is a, average duration of the OFF- period is b, and *N* is the number of frames sent during the ON - period. If we chose *a* much less than *b*, then generated traffic can be thought as very bursty [25].

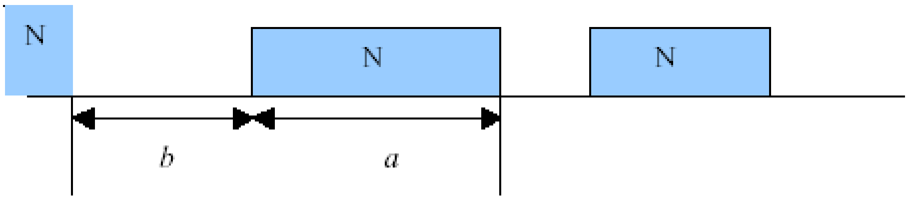


Figure 3. 15 Traffic Generated by ON-OFF Source Model [25]

3.2.3.6. CDPD MDBS MAC Process Model

MDBS MAC process model (Fig 3.16) is the peer part of CDPD M-ES MAC process model inside the MDBS. The MDBS informs M-ESs about the reverse channel status and decode status of the transmitted data packets via forward channel. These tasks are handled by using the *busy/idle* flag and the *decode status* flag in the forward channel stream.

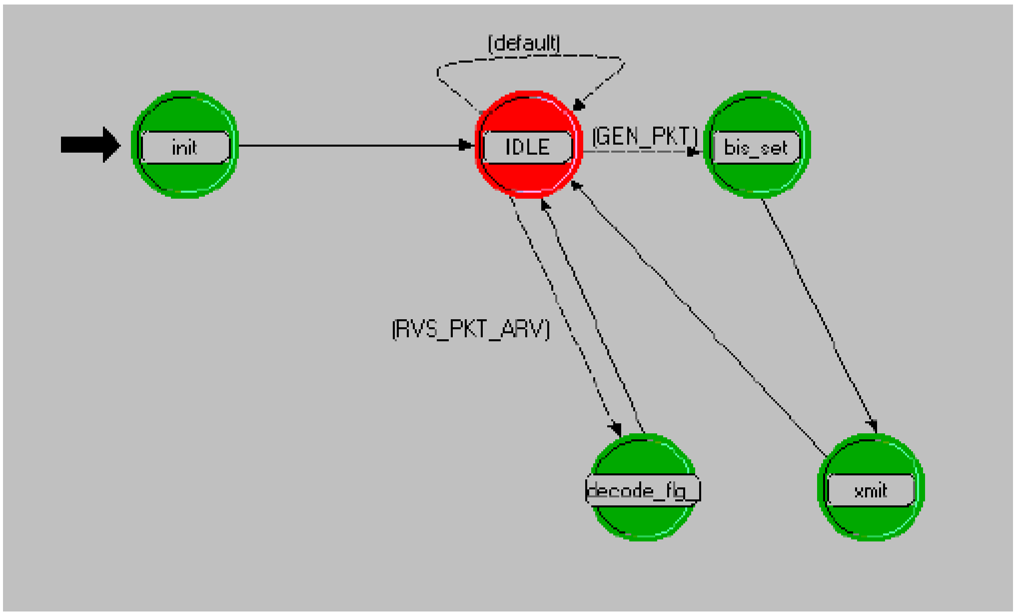


Figure 3. 16 CDPD MDBS MAC Process Model

In the *IDLE* state, process obtains the status of the reverse channel and decode status of the last transmitted data packet. In this state, if a packet arrives from any of M-ESs, process moves to the *decode_flg* state where it writes the decode status into the next control packet. If a new control packet is produced, then process enters the *bis_set* state. In this state, reverse channel status is written into the next control packet. Then, process moves to the *xmit* state where the MDBS sends the packet on the forward channel and discards the packet received from the reverse channel [25]. For the detailed description of the functions of each state, refer to TABLE 3.4.

Table 3. 4 CDPD MDBS MAC Process State Definitions [25].

Name	Explanation
init	In this state, required initializations are made.
idle	This states is a waiting state for incoming packets.
bis_set	According to the status of reverse channel, busy/idle flag is set.

decode_flg_set	In this state, decode flag is set according to the packet loss status.
xmit	Control packets are transmitted.

3.2.4. Cellular Model Custom Pipeline Stages

According to [25], in order to specify customized links OPNET provides an open architecture for each individual link. This architecture is referred to as the transceiver pipeline in OPNET.

3.2.4.1. Transceiver pipeline stages in OPNET

The radio transceiver pipeline consists of fourteen stages (Fig 3.17).

In this work, fading channel implementation of the prior CDPD model [21] is used to simulate a bursty wireless channel. The following is a brief introduction of the pipeline stages relative to thesis work [25]:

- **Transmitter antenna gain**

The purpose of this stage is to compute the gain provided by the transmitter's associated antenna, based on the direction of the vector leading from the transmitter to the receiver. According to [25], this result is typically used in Stage 7 for receiver power computation.

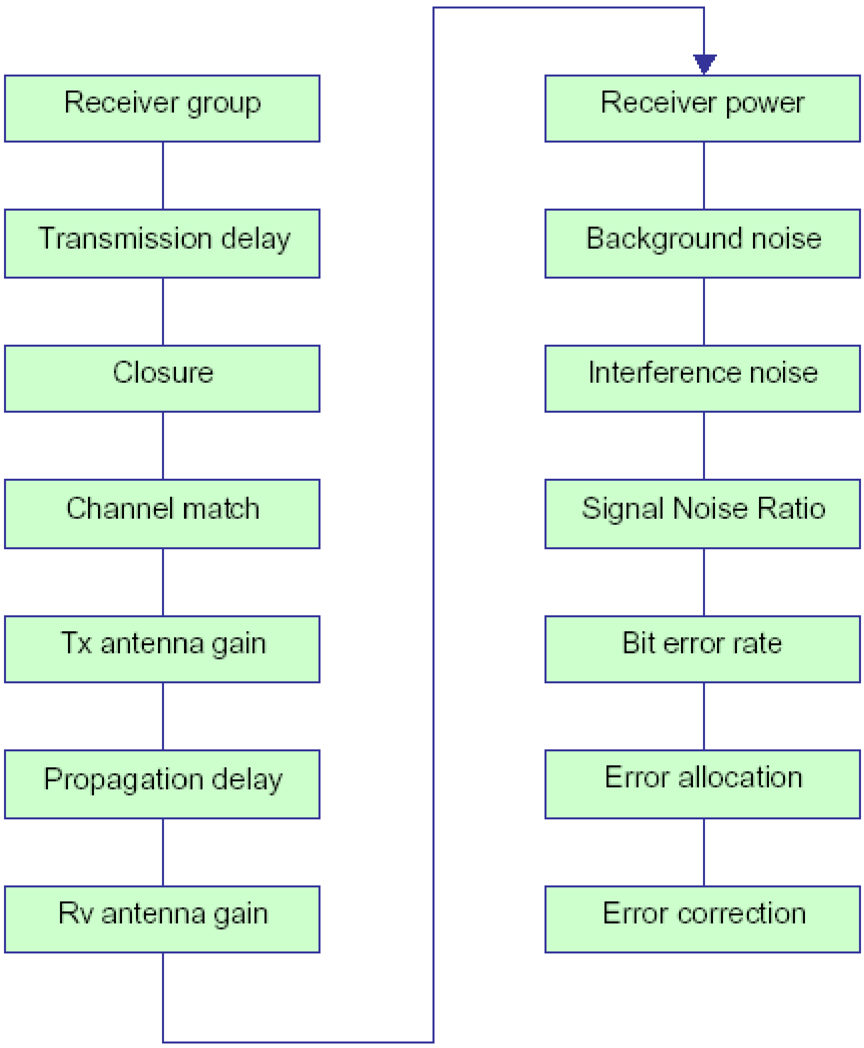


Figure 3. 17 Radio Transceiver Pipeline Stages [25]

- **Receiver antenna gain.**

In this stage, gain provided by the receiver's associated antenna is computed [25].

- **Receiver power.**

The purpose of this stage is to compute the received power of the arriving packet's signal (in Watts) [25].

- **Background noise.**

OPNET represent the effect of all noise sources except for other concurrently arriving transmissions [25].

- **Signal-to-noise ratio.**

In this stage, current average power SNR is computed. This calculation is usually based on values obtained during earlier stages, including received power, background noise, and interference noise. The SNR is a important parameter which indicates the level of receiver ability to correctly receive the packets content [25].

- **Bit error rate (BER).**

The BER stage is used to determine the probability of bit errors during the past interval of constant SNR [25].

- **Error correction**.

This is the final stage of the OPNET radio transceiver pipeline. According to the result of this stage, the kernel will either drop the packet or allow it to proceed into the destination node [25].

3.2.4.2. Mobile Radio Environment

[25] states that the data is transmitted on wire or via a fiber-optics cable in most networks. In mobile data networks, radio transmits data over the air. Air is subject to huge bit errors compared to wire interface. Also, as stated in [25], for a radio link, the power loss of the transmitted signal is due to three factors: propagation attenuation, severe fading, and background noise. All three have

severe impact on the signal-noise ratio (SNR) of the received frame arrived at the base station. Also, a fading signal will induce bursts of bit errors in the transmitted packets. This type of bit error model will allow a direct specification of the BER and the burstiness of the errors in the channel. The highly dynamic environment presents a unique challenge to the implementation of CDPD networks [15], [17]. As a result, an accurate simulation model for a wireless network should be able to reflect the propagation attenuation, fading, and background noise of the wireless channel. In this section, a brief introduction to each is given [25].

[25] incorporated the propagation delay, fading, and background noise models into three OPNET pipeline stages. These stages are *receiver power*, *background noise* and *snr stage*. The code is listed in files *cdpd_power.ps.c*, *cdpd_bkgnoise.ps.c*, and *cdpd_snr.ps.c*. The purpose of these custom pipeline stages is to model the physical environment in which a cellular system operates. The end result is to provide SNR calculations that take into account path loss in cellular environments and average fading effects.

In the other sections of this thesis work, we will abbreviate our OPNET model as Model-2.

3.3. CDPD OPNET Model Comparison

This work presents a comparison between two CDPD OPNET models (**Model-1** [21], **Model-2**). In general, **Model-2** is based on the structure of **Model-1**. Some process models in **Model-1** are used in our model without any change as described previously. Topology of a simple CDPD network is seen in Figure 3.18. **Model-1** and **Model-2** both modeled the wireless connection between **M-ES** and **MDBS**, i.e., the Media Access Control (**MAC**) layer of the CDPD protocol.

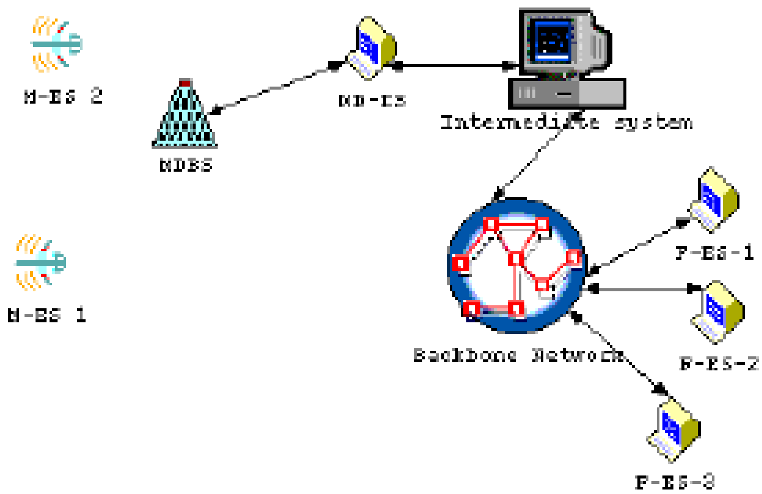


Figure 3. 18 Topology of a simple CDPD network [25]

The comparison between two models are achieved by using Poisson traffic in the network regarding the following statistic values:

- Average Queue Delay vs. Link Utilization (with MAC buffer size as infinite)
- Buffer Overflow Probability vs. Buffer Size (with %40 constant link utilization)
- Buffer Overflow Probability vs. Link Utilization (with MAC buffer size as 5)

In both models, Poisson traffic with packet size of **127** bytes and mean interarrival time of "**1**" seconds are used. Link Utilization is varied by changing either number of M-ES or link bandwidth. In addition to Poisson traffic, a 20-minutes long aggregated trace traffic data is available, which was collected from the TELUS Mobility CDPD network [25]. The trace traffic is actually not long enough to represent real CDPD traffic behavior, but gives a general idea on the traffic. **Model-1** and **Model-2** both use this trace also. Below sub-section describes the trace data.

3.3.1. Trace Data

A snapshot of the network configuration at the time the trace data set was collected is given in Fig. 3.19. [25] states that 10 mobile end systems registered in that cell during the trace data measurement. This network cell consisted of one MDBS connected to the CDPD backbone network, implying that almost all the traffic on the Airlink in this cell was visible from [25] monitoring point, except the traffic generated by the hidden terminals.

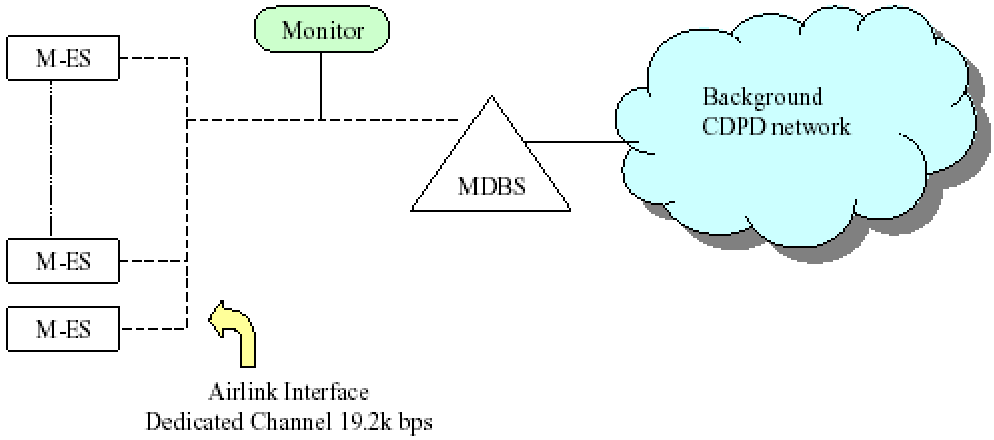


Figure 3. 19 CDPD Network Environment.

[25] obtained three sets of data from BCTel. According to [25], due to the limitation of the resources, only one set of traffic data was long enough for statistical analysis. Table 3.5 gives a summary description of the traffic data.

Table 3. 5 BCTel's CDPD network traffic Trace [25].

Duration	**Number of link layer frames**	**Number of bytes**	**Average traffic load**	**Network utilization**
20 minutes	1,281	152,439	1,016 bps	5,29 %

As stated in [25], trace traffic data were collected on the BCTel's CDPD network in downtown Vancouver area from 14:56:37.66 to 15:24:46.88 on June 12, 1998. During the period this data was collected on 10 M-ES's appeared in this cell, some M-ES's were more and some were less active. In the next chapters, the aggregated traffic will be used for the statistical analysis as a single traffic source. From the viewpoint of the MDBS, the aggregated traffic is the total input traffic [25].

Statistical analysis of the measured data

[25] uses two graphical methods to test the self-similarity of the wireless data traffic trace: R/S and variance-time plots:

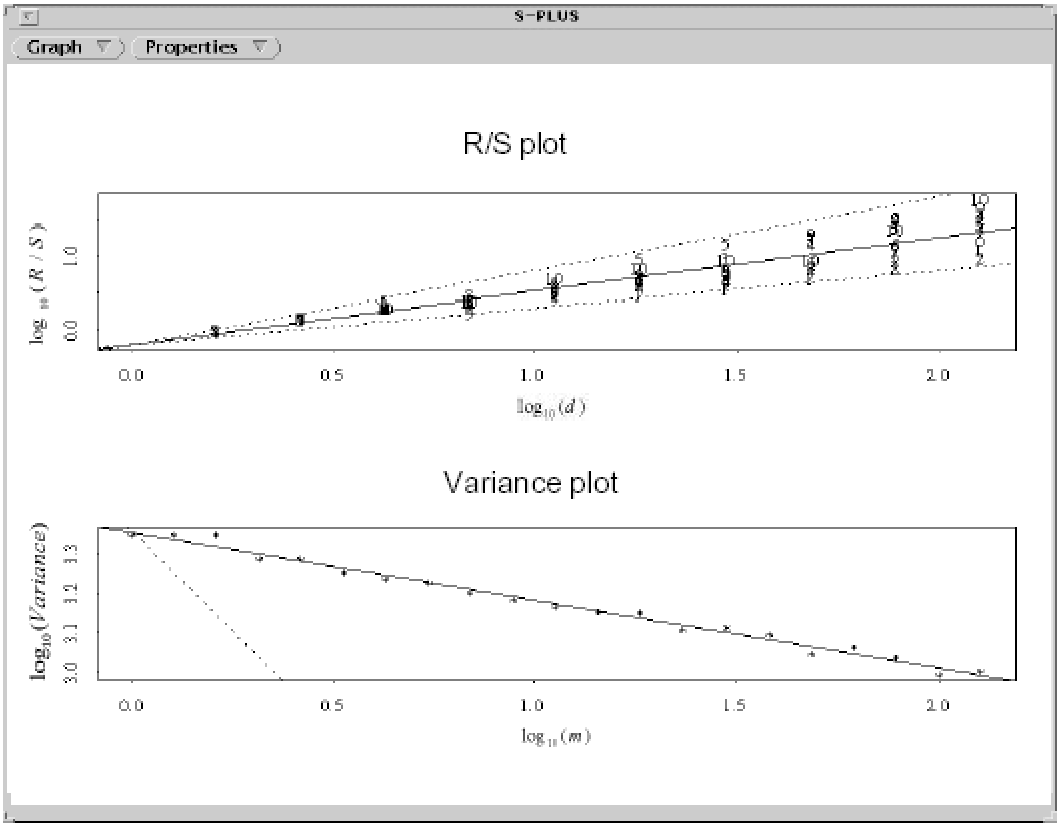


Figure 3. 20 Graphical Methods For Checking The Self-Similarity [25].

The Hurst parameter can be estimated directly from the corresponding R/S plot. As stated in [25], one can see that the value of the asymptotic slope of the

R/S plot is clearly between 0.5 and 1 (lower and upper dotted lines, respectively), with a simple least-squares fit giving $H \approx 0.80$.

The variance-time curve results in an estimate H of the Hurst parameter H of $H \approx 0.90$ [25].

These two graphical methods suggest that the traffic sequence is self-similar with self-similarity parameter $H \geq 0.80$.

3.3.2. Model Comparison

Model-2 has some significant modifications with respect to **Model-1.** These modifications are made according to CDPD specifications. As a result, **Model-2** represents a real CDPD network more closely. The modifications to **Model-1** are as follows:

1. Burst transmission of MAC blocks (uplink)

In the **Model-2**, reverse channel packets waiting in the MAC queue are transmitted up to a certain burst size threshold. In Model-1, there is no such threshold.

2. Exponential backoff

In the new model, exponential backoff algorithm is implemented.

3. Packet structures

Model-2 has 6 different packet structures used in either data transmission or control / sync information exchange. **Model-1** uses a part of these packet structures.

4. Frame segmentation and encapsulation into MAC layer blocks

In the new CDPD model, generated frames are segmented, inserted into MAC blocks and transmitted. Segmentation buffer is used when packets needs to be cut into smaller packets.

As a result, deaggregation of MES is achieved. In [25], since the important thing was to analyze the aggregated CDPD trace traffic, MES model of **Model-1** was modeled accordingly. In **Model-2**, deaggregetion is achieved and thus this gives flexibility to the MES nodes and CDPD network.

For Poisson traffic analysis, as a result, above modifications to **Model-1** combined do have a drastic effect on the system behavior especially for the *buffer overflow probability* parameters. In the new model, the values of buffer overflow probability are higher compared to the first model as can be seen from the below figures (Fig 3.22 & Fig 3.23). This model behavior is more similar to real CDPD network system behavior. For average queuing delay parameter, it can be seen from the Fig 3.21, there is a slight difference between two model's results. Queuing delay is measured with MAC layers having infinite buffer size. Results seem reasonable because modifications to Model-1 will not bring much effect to this parameter.

For trace traffic analysis, Model-2 presents higher buffer overflow probabilities compared to Model-1. On the other hand, as for average queuing delay, there is almost no difference between two models as in poisson traffic analysis. While this shows that both models present similar queuing delay behavior, they give quite different results for buffer overflow probability behavior due to new MAC layer models.

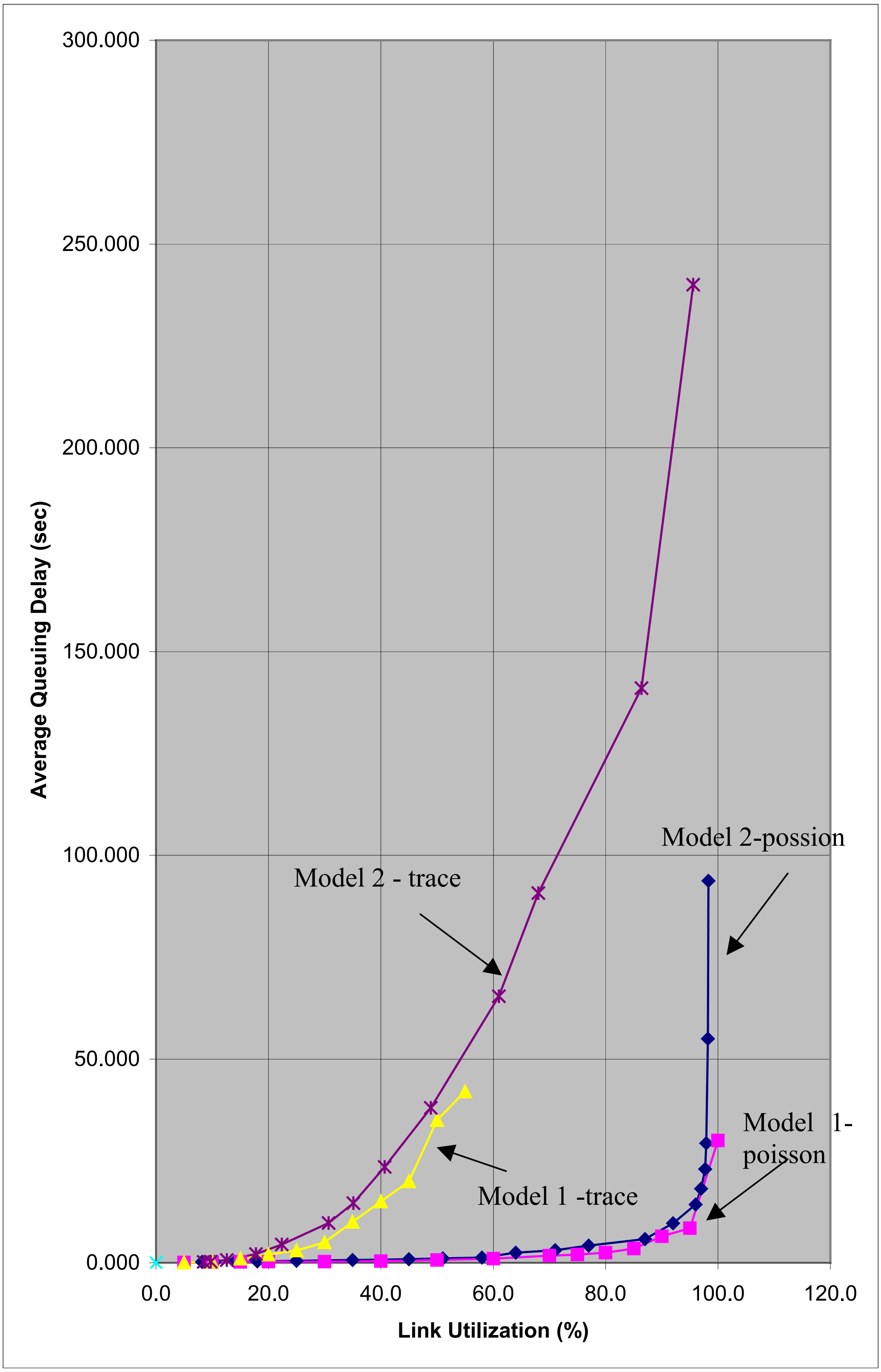


Figure 3. 21 Model-1 vs. Model-2 (infinite buffer size)

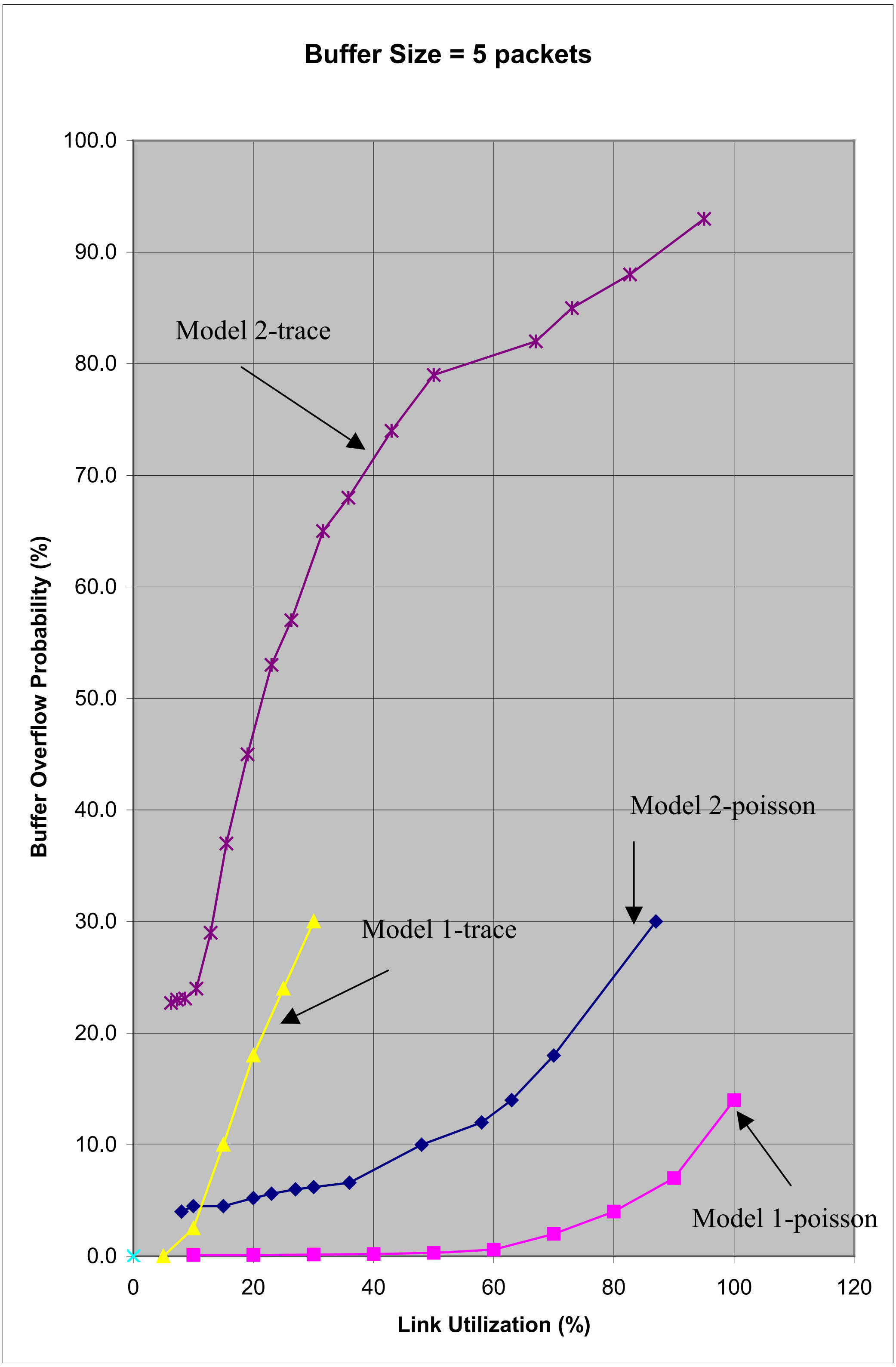


Figure 3. 22 Model-1 vs. Model-2 (Buffer size = 5)

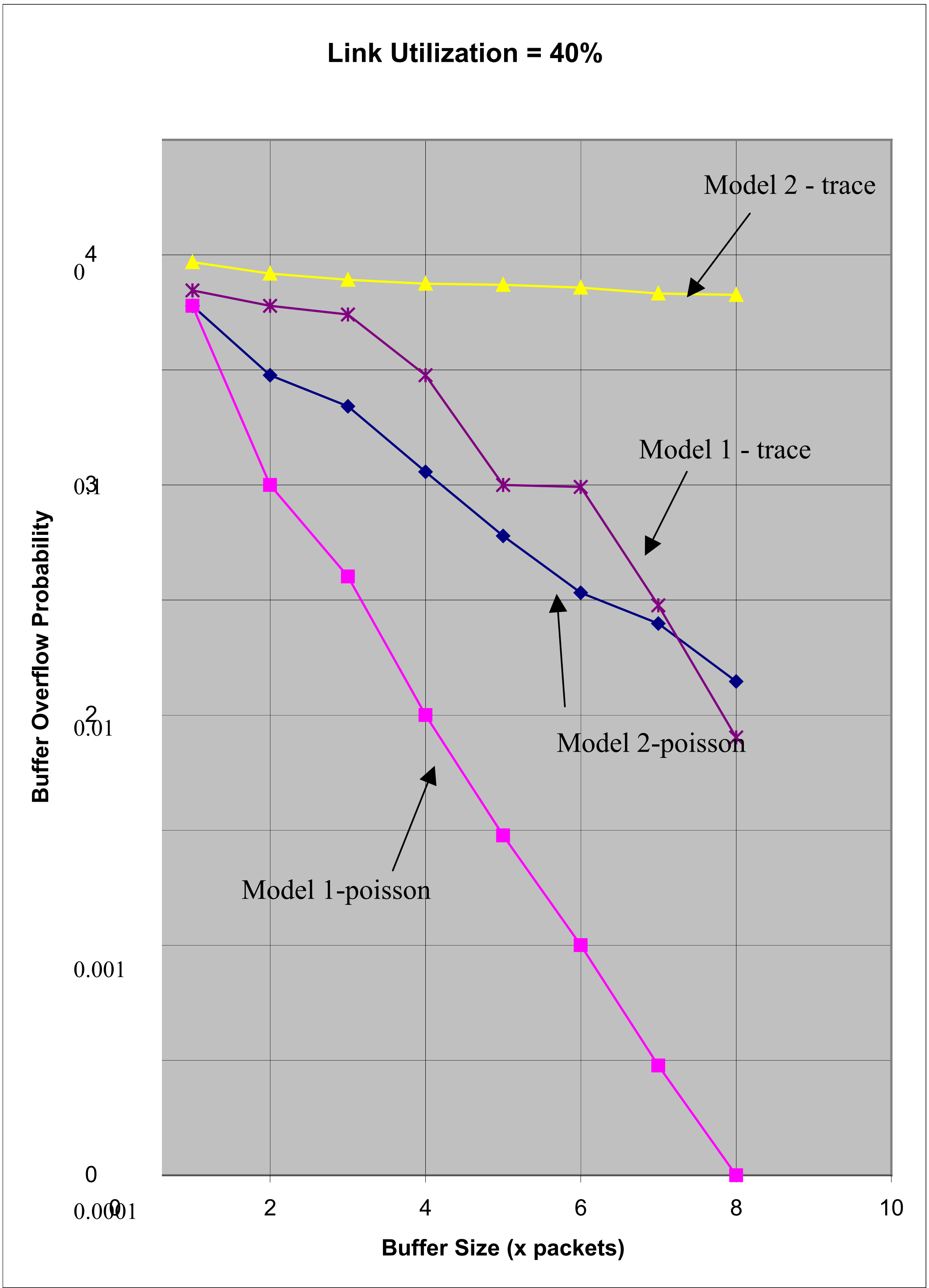


Figure 3. 23 Model-1 vs. Model-2 (Link Utilization = 40 %)

In the next chapter, we introduce a synthetic traffic model in OPNET in order to model CDPD trace traffic as close as possible. Then, we apply a traffic having higher level of burstiness to the Model-2 and observe the M-ES MAC layer's buffer utilization.

CHAPTER 4

OPNET TRAFFIC MODELING AND M-ES PERFORMANCE UNDER BURSTY TRAFFIC

4.1. OPNET SYNHTETIC TRAFFIC GENERATION

In this part of our work, the aim is to generate a synthetic CDPD traffic in order to model trace data traffic applied upon *Model-2*. The trace data was collected from Telus Mobility CDPD network [11]. During the time period when these data were collected, 10 mobile end systems appeared in the cell. Some were more and some were less active. The trace data represents aggregated traffic (the total input traffic to the mobile data base station (MDBS)). In [11], the trace input data was applied to the *Model-1* and related results were collected. According to [11], this wireless data traffic tends to have a self-similar behavior, and it is statistically different from traffic generated by traditional traffic models. On the other hand, the traffic trace was too short to warrant a more definite conclusion.

We applied the trace traffic data to the Model-2 and collected the following statistics from the M-ES node based on [11]:

- Average Queue Delay vs. Link Utilization (with MAC buffer size as infinite)
- Buffer Overflow Probability vs. Buffer Size (with %40 constant link utilization)
- Buffer Overflow Probability vs. Link Utilization (with MAC buffer size as 5)

4.1.1. Design and Modeling

Knowing the self-similar behavior of the CDPD traffic based on [11], in the initial phases of OPNET synthetic traffic generator design, we focused on the synthetic traffic models, which present self-similar behavior (e.g. FGn (Fractional Gaussian Noise), FARIMA (Fractional ARIMA models), Wavelets, ON-OFF processes, e.t.c.). From these traffic models, we selected to implement ON-OFF traffic generator because of its simplicity of implementation in OPNET with respect to the others.

OPNET ON-OFF process model can be seen in Fig 4.1. This process model uses the attributes in Fig 4.2:

- ON State time has "pareto" distribution with location **1** and shape **1**.
- OFF State time has "exponential" distribution with mean **7**.
- Distribution of interarrival time of each packet is "exponential" with mean **0.1** seconds.
- Distribution of Packet size is "exponential" with mean **127** bytes.
- Segmentation size is **132** bytes.

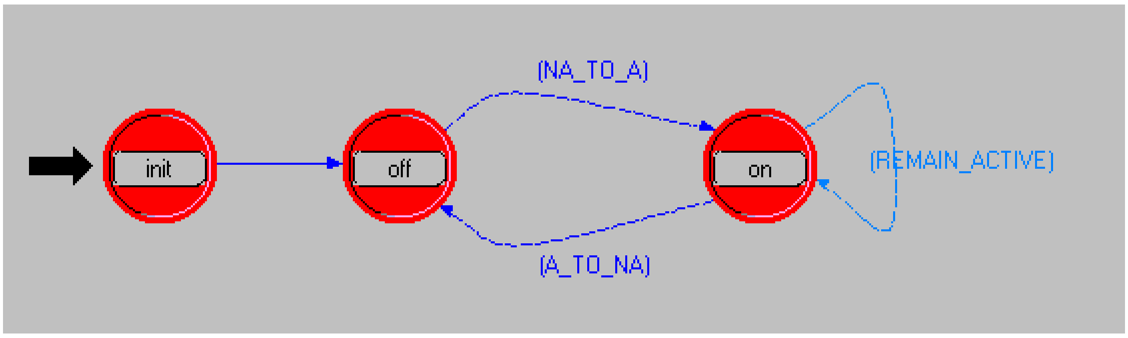


Figure 4. 1 OPNET ON-OFF process model

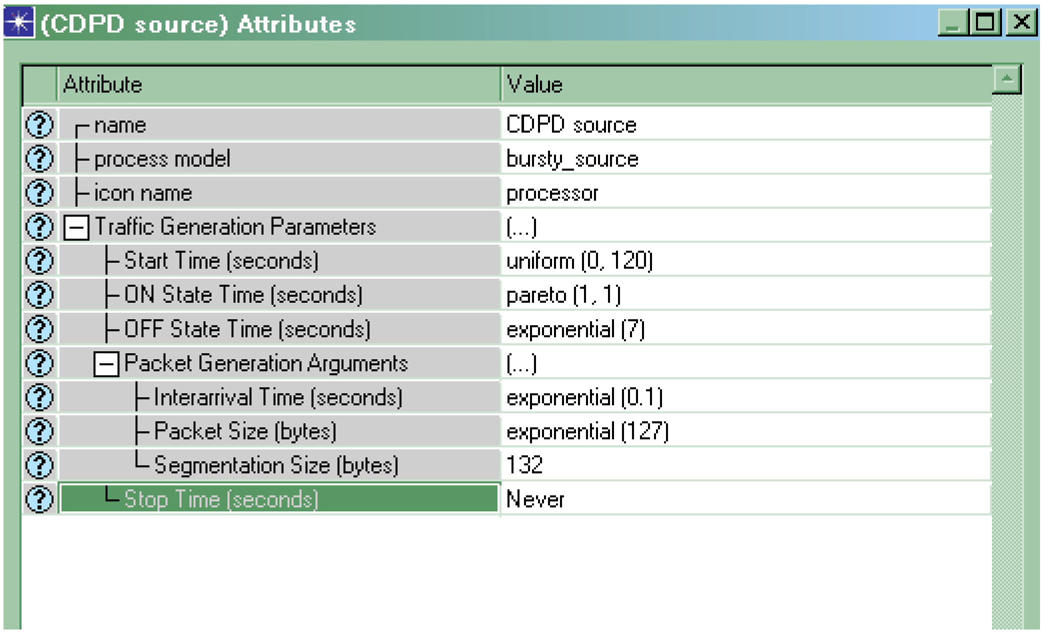


Figure 4. 2 CDPD source attributes

The Pareto distribution could be used to the model interarrival times when the traffic is bursty. The Pareto distribution is a distribution with memory, heavy tail, and strong burstiness. Depending on the value of one of its parameters it can have finite mean and infinite variance. The usage of pareto distribution in ON State time gives burstiness to the synthetic traffic model. As a result, ON-OFF process with either the ON period or the OFF period having a pareto distribution is self-similar [19].

In order to obtain the most proper model, simulations with different combinations of pareto and exponential distributions were done with fixed packet size of 127 bytes, which is the average packet size obtained from the trace data, and obtained simulation results were compared with the trace traffic simulation results, i.e. ad-hoc trial. The combinations mentioned above are as follows:

1. ON State time: **pareto** (shape, location)-OFF State time: **pareto** (shape, location)-Interarrival Time: 0.1 or 1 sec.

2. ON State time: **pareto** (shape, location)-OFF State time: **exponential** (mean value)-Interarrival Time: 0.1 or 1 sec.
3. ON State time: **exponential** (mean value)-OFF State time: **pareto** (shape, location)-Interarrival Time: 0.1 or 1 sec.
4. ON State time: **exponential** (mean value)-OFF State time: **exponential** (mean value)-Interarrival Time: 0.1 or 1 sec.

Among the above combinations, Number2 with mean interarrival time 0.1 sec was selected as being most suitable with suitable mean value, shape, and location values, which are determined by adhoc method. With the other combinations, we observed that obtained simulation results did not match the trace traffic results regarding all statistics mentioned above. For instance, Number1 gives less buffer overflow probability than our trace traffic does.

4.1.2. Results

After implementation of OPNET ON-OFF process model, some statistical simulations were ran in the CDPD test environment (Fig 4.3). Fig 4.5, Fig 4.6, and Fig 4.7 show the statistical results after simulations.

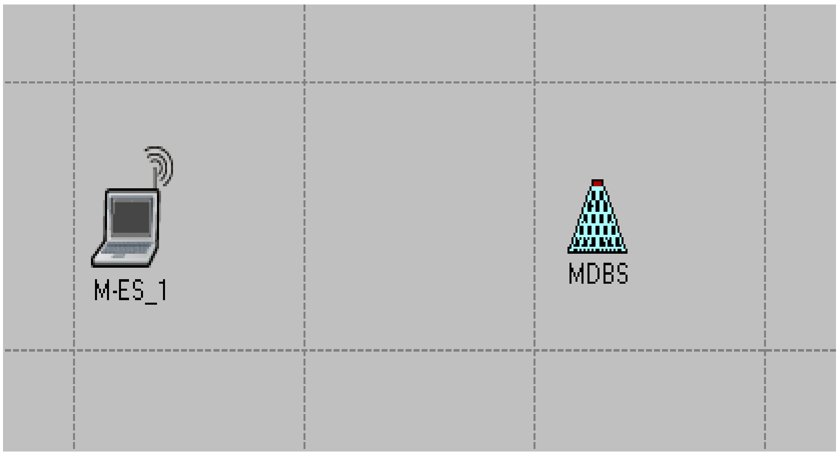


Figure 4. 3 CDPD Test Environment

In the simulations, Link Utilization was changed by varying the link capacity in OPNET model between M-ES (Mobile End System) and MDBS (Mobile Data Base Station), which is equivalent to varying the traffic load of a single user. Decreasing link capacity, we increased the link utilization and as a result, the traffic load. Fig 4.4 shows an example of how to do this in OPNET.

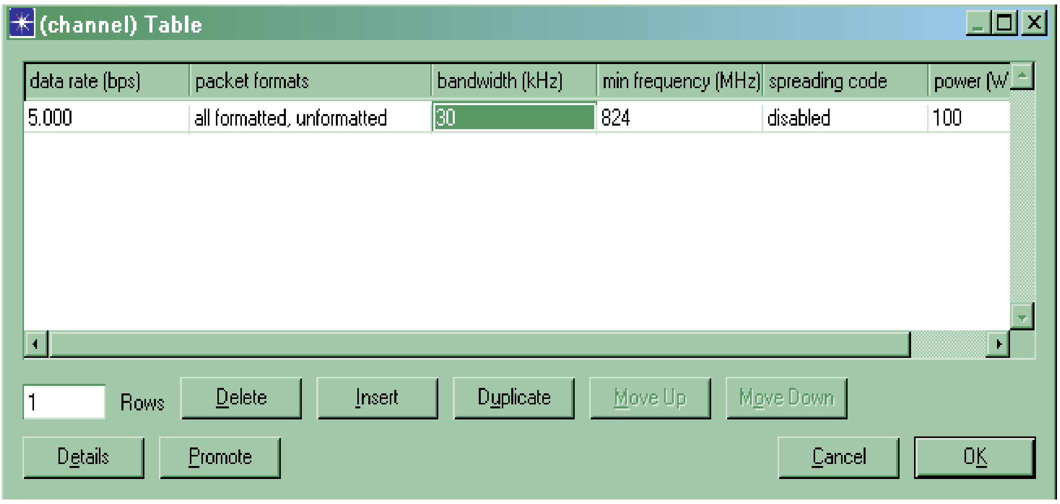


Figure 4. 4 Changing Link Data Rate in OPNET

4.1.3. Model Verification

The verification of the synthetic OPNET traffic generator is done based on the above M-ES statistics collected from the CDPD test environment. The statistical simulation results from Model2-synhtetic are compared to those from Model2-trace within %95 confidence interval and with ± %10 error bound.

4.1.4. Conclusion

As seen from the figures above, implemented OPNET ON-OFF model with proper attribute settings can represent the CDPD trace traffic data collected from Telus Mobility. The statistical simulation results from Model2-synthetic differ from the ones of Model2-trace by at most %10 in Fig 4.6 for a few statistical values of link utilization's values.

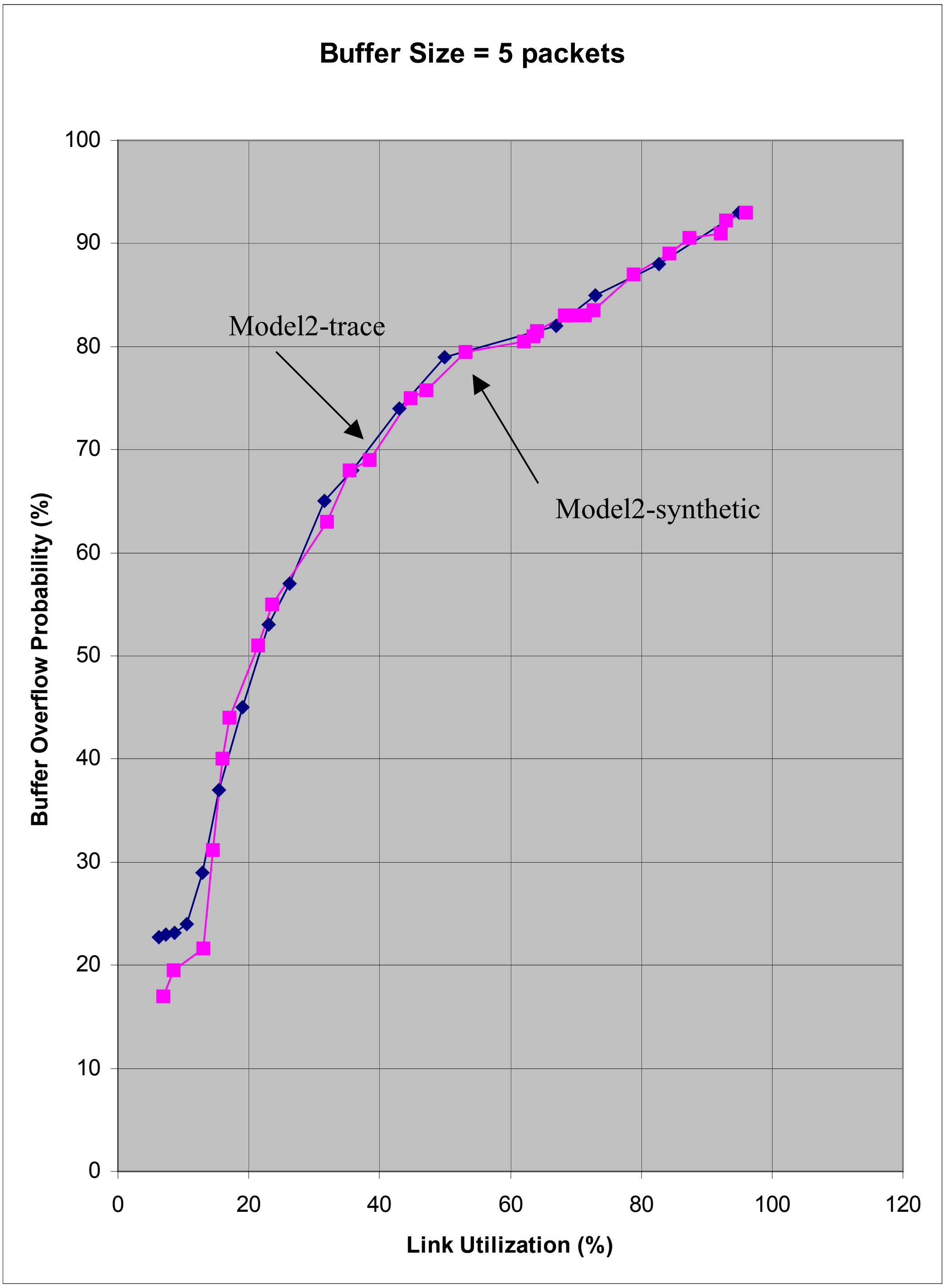


Figure 4. 5 Model2-Trace vs. Synthetic (Buffer Size = 5)

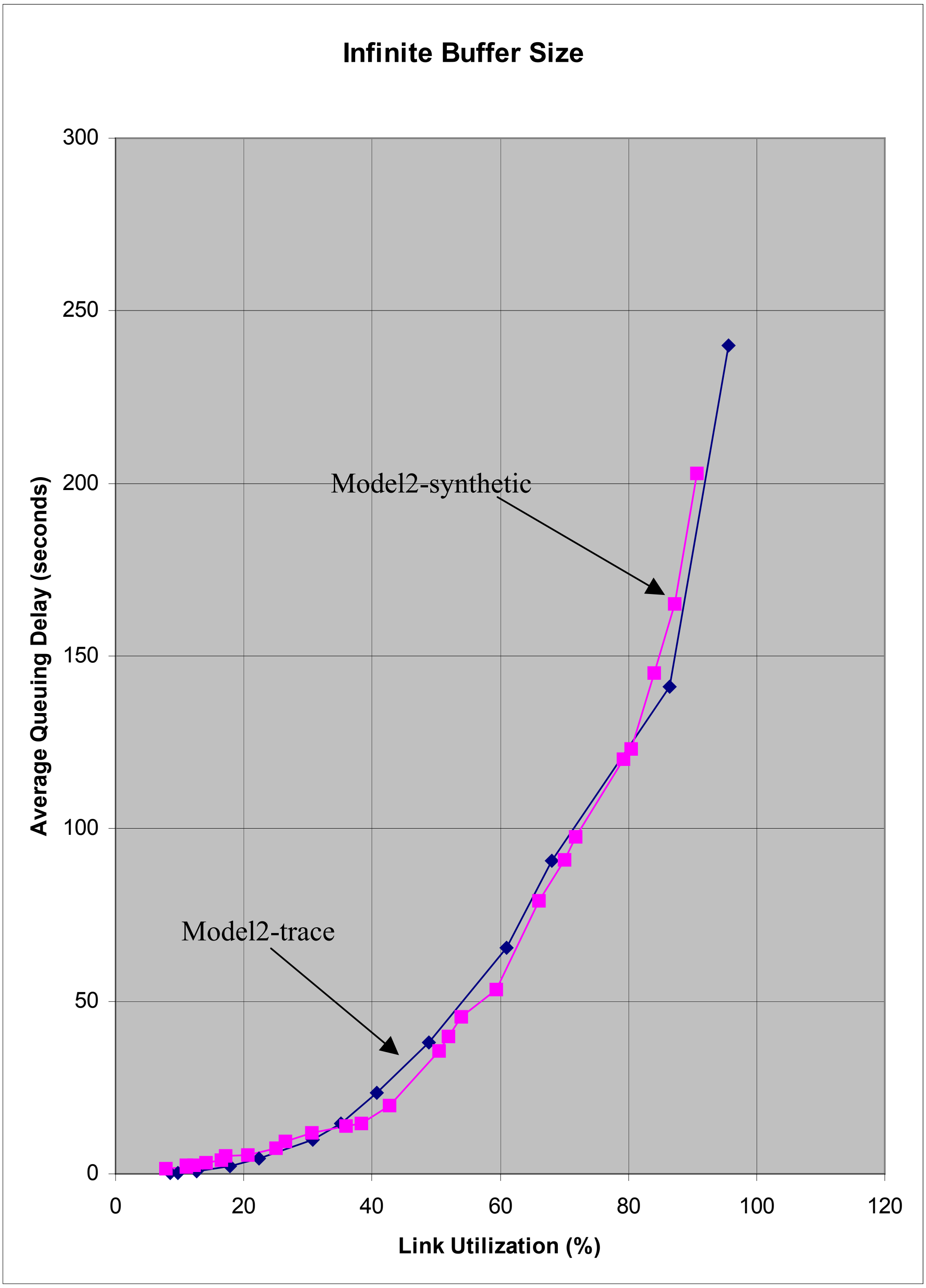


Figure 4. 6 Model2-Trace vs. Synthetic (With Infinite Buffer Size)

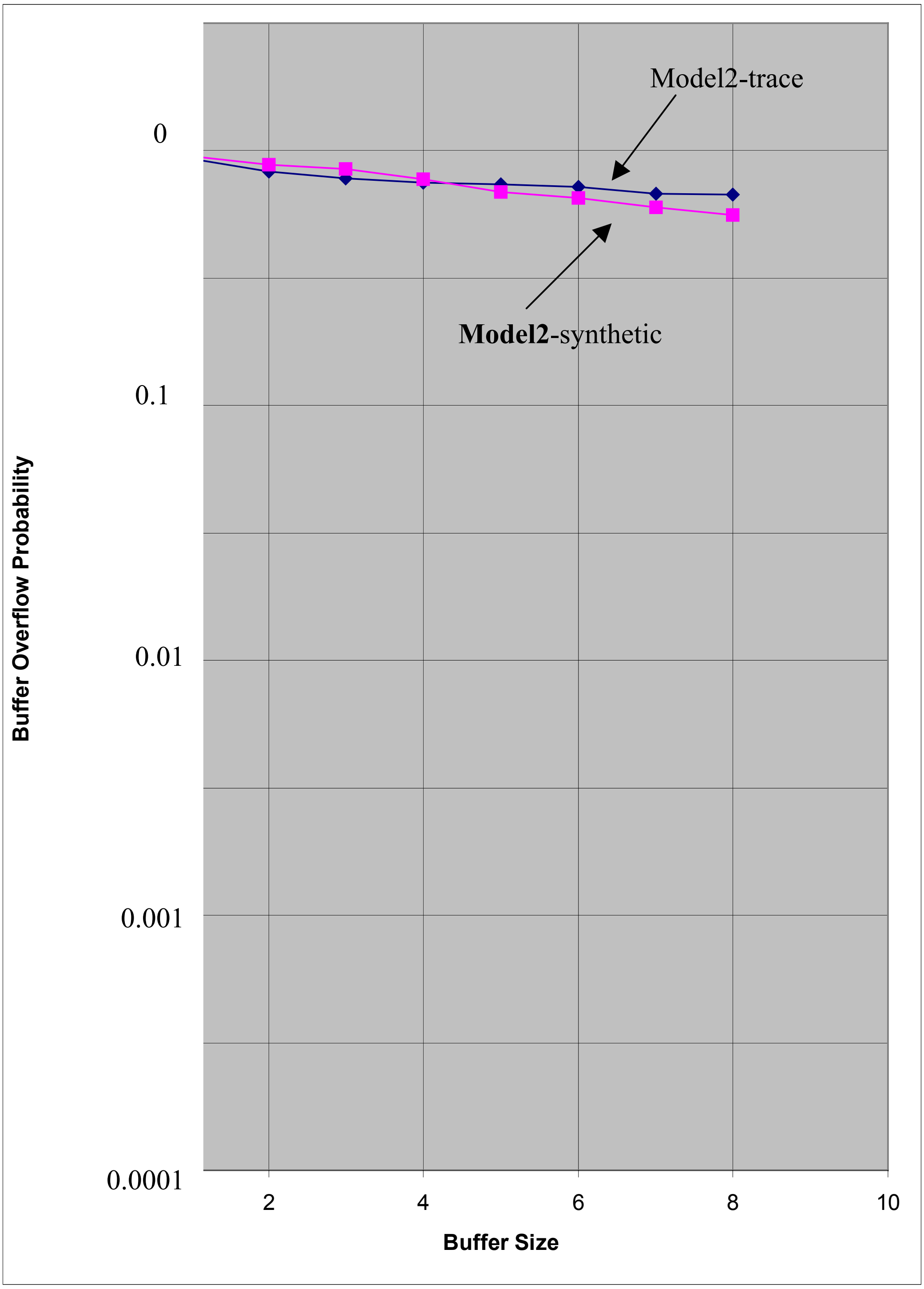


Figure 4. 7 Model2-Trace vs. Synthetic

4.2. M-ES MAC BEHAVIOUR UNDER BURSTY TRAFFIC

In this part of the work, we applied synthetic and burstier traffic to the Model2 in order to observe the M-ES MAC layer's buffer utilization and thus observing CDPD behavior under fairly bursty traffic. For this purpose, the following statistics were collected:

- Buffer Overflow Probability vs. Buffer Size (with %40 constant link utilization)
- Buffer Overflow Probability vs. Link Utilization (with MAC buffer size as 5)

Traffic Configuration Parameters are set as seen in Fig 4.8.

In order to generate bursty traffic, we used ON-OFF traffic modeling. ON and OFF state times both have exponential distributions. Smaller values of ON state time generate more bursty traffic. Mean value of packet interarrival time is quite small in order to generate packet bursts when ON-State is active.

4.2.1. Results

After applying bursty traffic to our CDPD network model, we obtained the below figures showing the relationships between buffer overflow probability and link utilization&buffer size. Fig 4.9 shows the CDPD network simulation environment in OPNET. Simulation run-time is 3 hours.

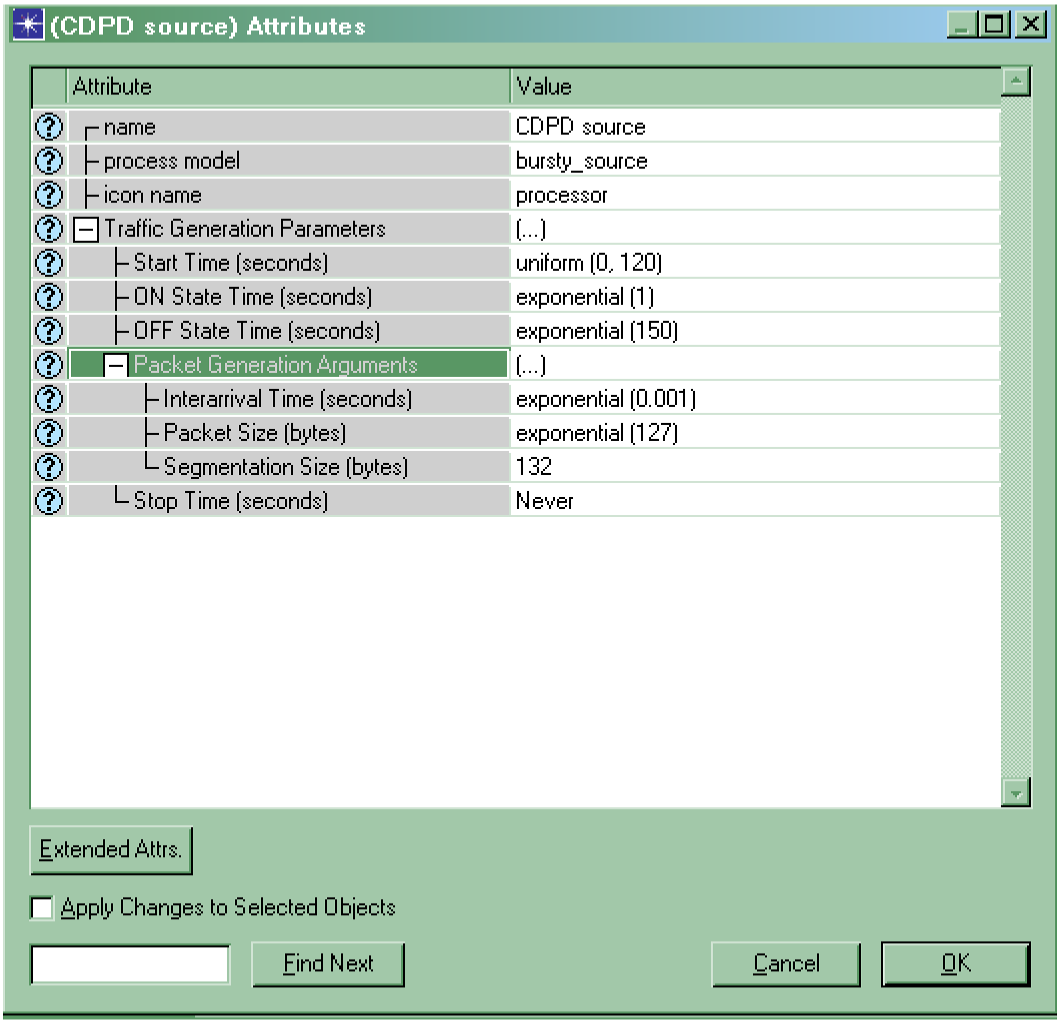


Figure 4. 8 Bursty traffic configuration parameters

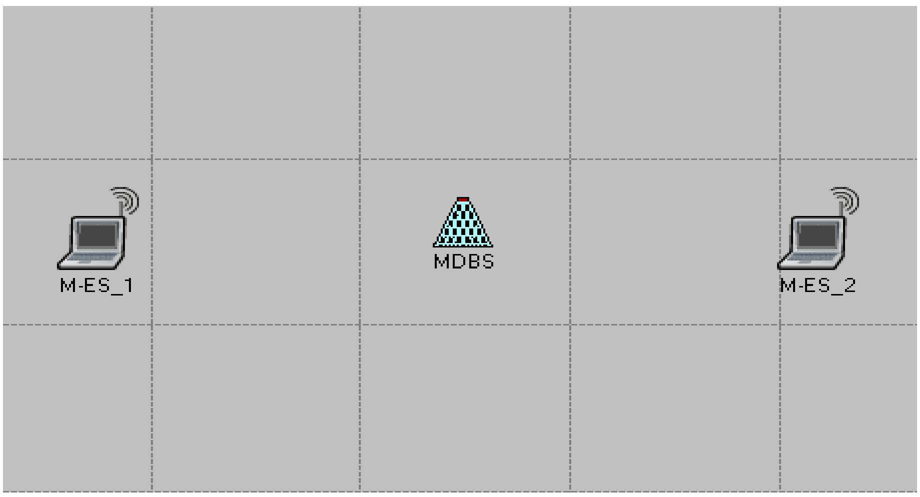


Figure 4. 9 CDPD Test Environment

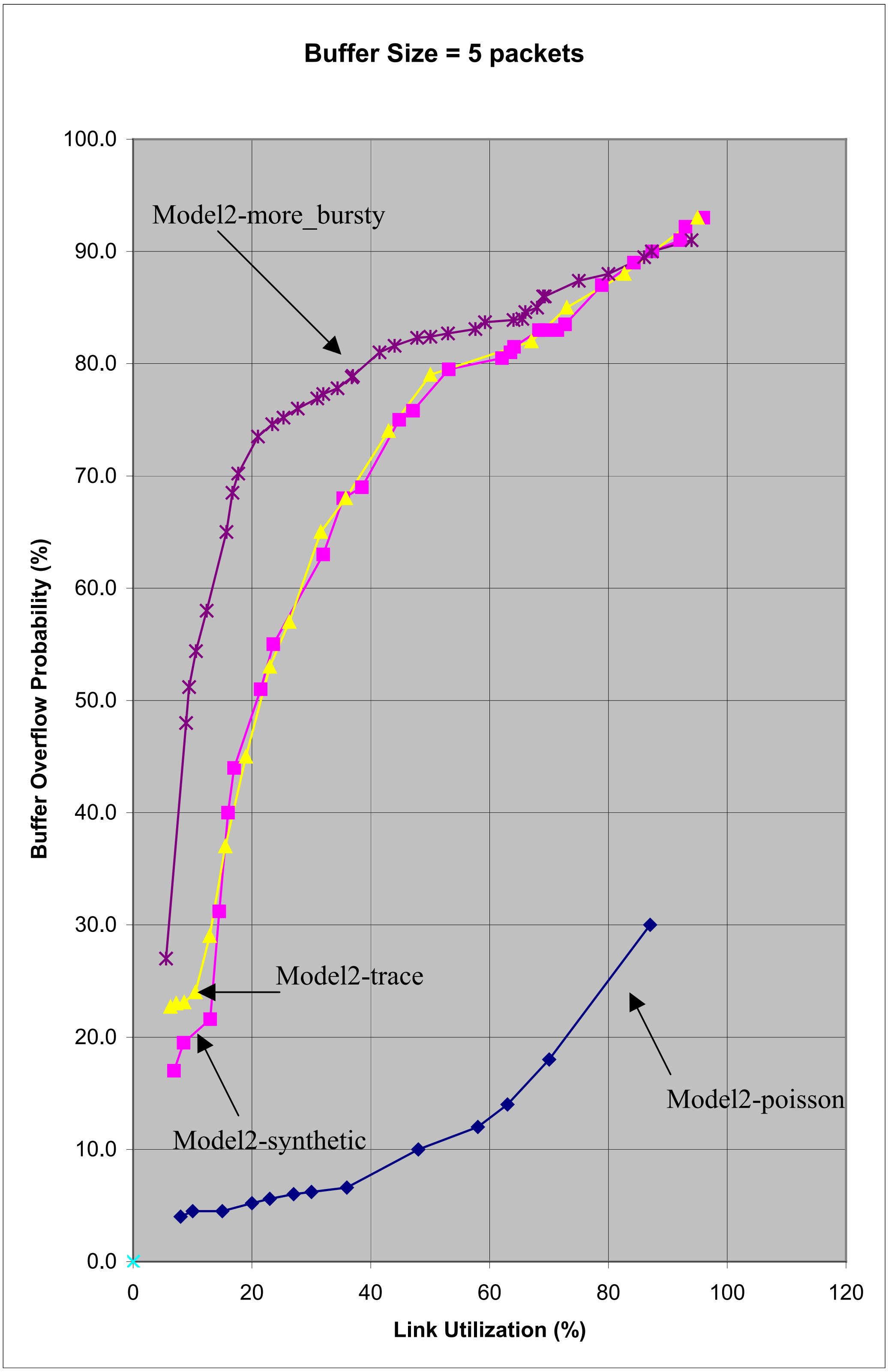


Figure 4. 10 Model2-More_Bursty Traffic Model1

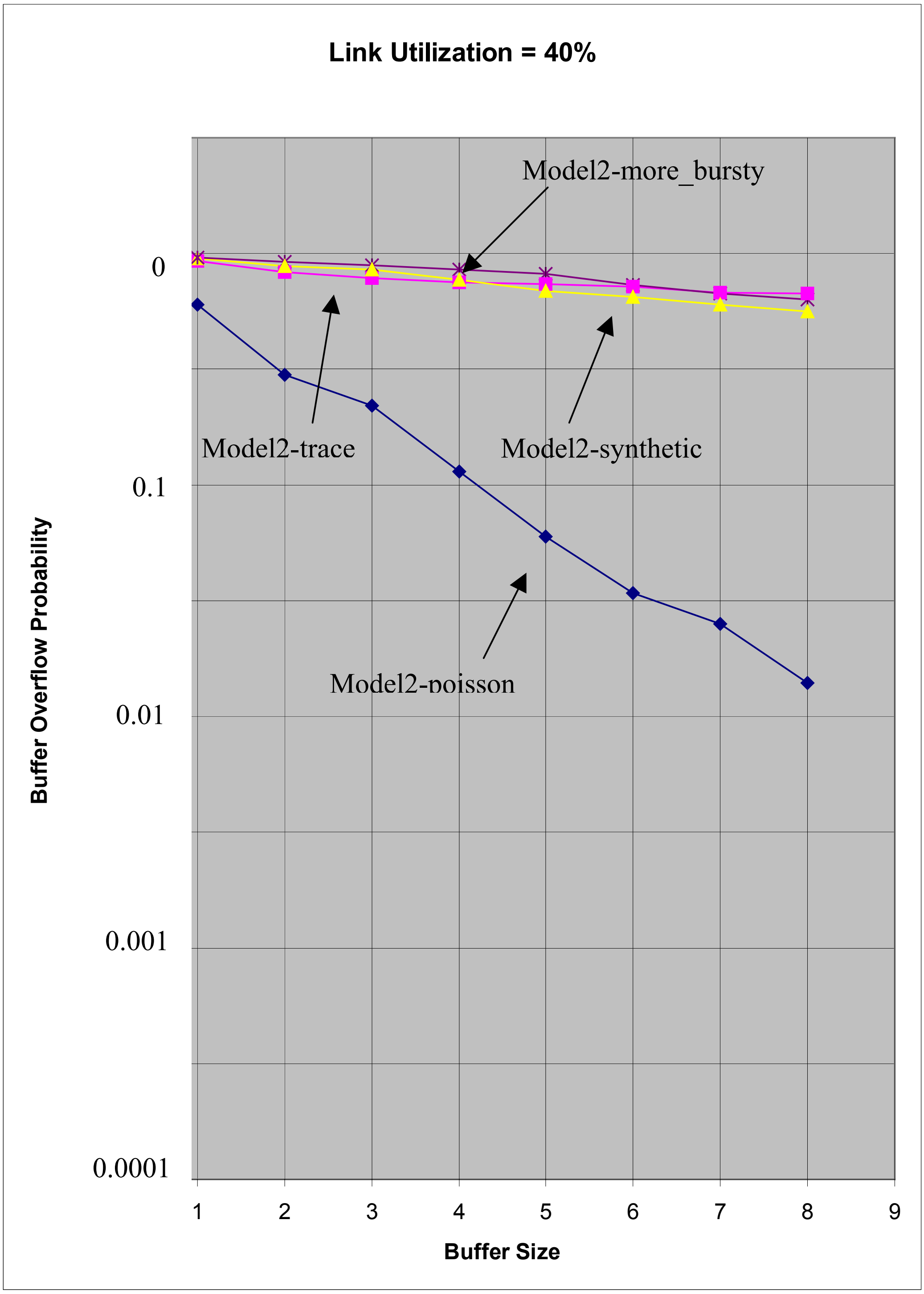


Figure 4. 11 Model2-More_Bursty Traffic Model2

For link utilization below 50%, Model2-more_bursty traffic (MBT) gives much higher buffer overflow probabilities compared to the others (Fig 4.10). For the other link utilization values, there is no much difference between three simulation results (synthetic, trace and more_bursty). As for the buffer size vs. buffer overflow probabilities graph, up to the buffer size of 5, we observe that MBT gives slightly higher buffer overflow probabilities (Fig 4.11). For more than this buffer size value, MBT buffer overflow probability graph finds a place between Model2-synthetic and Model2-trace simulation results.

4.2.2. Conclusion

Based on the work done in this part, we can state that for lower values of link utilization statistic (less than %50), we need more buffer capacity as the traffic burstiness increases. As a general remark, it may be suitable to use this network under lower wireless link utilization in order to avoid undesired packet loss.

CHAPTER 5

CONCLUSIONS

In this study, first of all we modeled a CDPD network model, which consists of M-ES and MDBS nodes, using OPNET simulation tool. In this modeling, we tried to apply CDPD standard specifications to the model as much as possible. This model was compared to the prior CDPD model by M. Jiang. We generated a synthetic traffic model based on ON-OFF traffic pattern in order to model CDPD trace data traffic from Telus Mobility CDPD network. In order to validate our synthetic traffic model, we applied the trace data traffic to our CDPD network model and collected related results. Validation was based on these results. We knew that the trace data traffic was bursty. In order to investigate the buffer performance of M-ES MAC layer under a traffic which has a higher level of burstiness we modeled another synthetic traffic and applied to the OPNET CDPD network model.

One outcome of this work is that we have a CDPD network model in OPNET resembling a real CDPD network as much as possible. This model can be used for further investigations in the area of CDPD networks.

Another outcome is that we succeded to model the trace data traffic using ON-OFF model, which uses pareto and exponential distributions. This synthetic traffic model is able to capture the self-similar characteristic of measured network traffic (trace data traffic). Although the trace traffic was not long enough, our model will form a basis for the mathematical model of a real CDPD network traffic.

As a final outcome, by simulating the wireless data network using actual traffic trace and synthetic traffics, we concluded that genuine traffic produces longer queues and thus requires larger buffers in the network's switching elements due to self-similar characteristics of the CDPD traffic. We can state that for lower values of link utilization statistic (less than %50), we need more buffer capacity as the traffic burstiness increases. As a general remark, it may be suitable to use this network under lower wireless link utilization or it may be suitable to use larger buffers in order to avoid undesired packet loss.

As can be seen from our simulation results, the delay performance obtained with the trace traffic and our bursty synthetic traffics is different from that predicted by Poisson arrival processes. In the circumstance of moderate and high network utilizations, short-range dependent traffic sources (Poisson sources) model underestimated queueing delays grossly.

Possible future work related to this study may include:

- CDPD Mobility Modeling in OPNET, which includes moving M-ES, multiple MDBSs and handoff algorithm.

- Working on longer traffic trace that may give more accurate results.

- Incorporation of IP and application layers into the CDPD OPNET model.

CDPD is losing its popularity currently because of its low speed (19.2 kpbs) compared to 1xRTT, GPRS and their successors although it is advantageous in coverage and cost. Till the end of 2005, it is very likely that the most of CDPD service providers will shut down their networks. As a result, more works will not be needed on CDPD, naturally.

However the work in this study can be adapted to the other wireless mobile networks for further researches in the area of traffic modeling and buffer performance.

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