Evaluation of Session Handoffs in a Heterogeneous Mobile Network for Pareto based Packet Arrivals

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***Abstract*—Efficient methods for analyzing vertical handoffs for IP based data sessions are essential for emerging heterogeneous data networks. This is mainly due to the high frequency of vertical handoffs experienced by roaming users in such internetworked environments. This paper presents an analytical approach for evaluating vertical session handoffs in such an environment where the packet arrivals follow a Pareto distribution. The reason behind this assumption is due to the fact that probability distributions with long tails have proven to be better suited for modeling packet inter-arrival times for Internet based data traffic. The analysis and evaluation are applied for a framework previously designed by the authors' for interworking between heterogeneous data networks. Finally, the results obtained from this analysis are compared against the results obtained from a classical queuing model where Poisson arrivals and exponential service times are assumed.**

Keywords- Queuing Networks; Pareto Distribution; Poisson Distribution; IMS; UMTS; CDMA2000; WiMAX; SIP; Mobile IP;

I. INTRODUCTION

The future 4th Generation (4G) network will be essentially a collection of interworked all-IP based heterogeneous data networks that provide ubiquitous data services and relatively high data rates. Such an environment could be achieved by interworking 3G cellular networks (i.e., the Universal Mobile Telecommunications System (UMTS) and the Code Division Multiple Access 2000 standard (CDMA2000) based systems) with Broadband Wireless Access (BWA) networking technologies (e.g., WiMAX) [1].

Therefore, within the context of a 4G architecture, BWA networks essentially operate as a complementary technology for 3G cellular data networks [2]. In such environments where dissipate networks are interworked, ongoing call sessions to/from roaming users are frequently subjected to vertical handoff. As a result, appropriate mechanisms capable of evaluating and analyzing vertical call/session handoffs for such IP data traffic is highly desirable.

Recent studies have strongly indicated that the basic assumptions made for analyzing Poisson arrivals in the classical queuing theory do not universally hold for Internet traffic [3] [4] [5]. According to available resources in the area of analyzing and characterizing Internet traffic, long-tailed distributions serve as better models for packet inter-arrival times and service lengths for Internet traffic [6] [7] [8] [9]. Despite many contributions that have been made in this area, to the best of our knowledge, a method for analyzing vertical handoff for IP based call sessions for a roaming user in a heterogeneous networking environment is least unexplored.

Hence the key contribution of this paper lies in developing an analytical model for analyzing vertical session handoffs in a heterogeneous mobile networking environment where the packet arrivals follow a Pareto distribution. The analysis studies a *G/M/1* queue, where *G* is Pareto (rather than Poisson) to model data sessions that are subjected to vertical handoffs. The vertical handoff mechanism and heterogeneous networking platform used for the analysis is based on an authors' previous contribution [10]. The significance of our proposed heterogeneous networking platform is that it uses a novel approach, that is, the use of the 3GPP's IP Multimedia Subsystem (IMS) for supporting real-time session negotiation and management [11].

The reminder of this paper is organized as follows. The next section provides an overview on Internet traffic modeling. Next is a brief introduction the interworking platform and the vertical handoff mechanism used for the analysis. Subsequently the sections on vertical handoff analysis and the numerical results follow prior to the concluding remarks.

II. INTERNET TRAFFIC MODELING

It is a well known fact that the basic assumptions used for modeling Poisson arrivals do not hold for today's Internet. The main reasons for such behavior is since the Internet traffic has indicated one or more of the following related characteristics: self-similar (or fractal) traffic traces, long-range dependence, burstiness on multiple scales, and long or heavy-tailed packet inter-arrival times or service requirements [12].

Self-similarity implies that the traffic looks the same over any time scale. Furthermore, as first shown in [3], Poisson traffic does not have the same characteristic. Long-range dependence is defined with respect to the autocorrelation function of a stationary discrete-time stochastic process, $R(k)$. It measures the level of correlation of the process with itself and measured k periods away. The process is said to be long-range dependent if $\Sigma_k R(k) = \infty$, thus implying that there is at best a slow and non-exponential decline in the autocorrelation function with increasing lags k.

Furthermore, it may be argued that a self-similar process is also long-range dependent. The Hurst parameter is often used to describe the degree of self-similarity in long-range processes [12]. The concept of burstiness means that packets arrive in

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several short inter-arrival times followed by a much longer time. Examples of long-tailed distributions are the Pareto, the log-normal, the folded Cauchy, and the DFR form of the Weibull. In this analysis, a method for studying Pareto queues is presented.

The standard form for the two-parameter Pareto distribution function defined over the nonnegative real numbers can be written as:

$$F(x) = 1 - 1\Big/\left[(\alpha + x)^{\beta}\right] \forall(\alpha, \beta \rangle 0) \tag{1}$$

As a critical motivation for the subsequent procedure, such a distribution function can be directly derived as a gamma (α, β) mixture of ordinary exponential densities. With no loss in generality, the one-parameter version of the Pareto can be given as [13].

$$F(x) = 1 - 1\Big/\left[(1 + x)^{\beta}\right] \tag{2}$$

Therefore, the corresponding density function is:

$$f(x) = \beta\Big/\left[(1 + x)^{\beta+1}\right] \tag{3}$$

and it is shown that the Pareto is indeed a long-tailed distribution, where β measures the initial rate of decline of the density function curve [13]. In the following scenario, a Pareto arrival distribution into the queuing system is considered. From the standard analysis of a G/M1 queue, the steady-state probability for a Q number of customers in the system just before an arrival is given for all nonnegative n as [14]:

$$\Pr\{Q = n\} = q_n = (1 - r)r^n \tag{4}$$

For *Pareto/M/1*, the usual approach for obtaining the stationary delay time distributions and system size probabilities requires solving a root finding problem involving the Laplace-Stieltjes Transform (LST), $A^*(s)$, of the inter-arrival time distribution function [14], [15]. Thus r is the root of the fundamental branching process equation obtained by solving for z is:

$$z = A^*[\mu(1 - z)] \tag{5}$$

where $1/\mu$ is the expected service time [14]. The system utilization, ρ, which is λ/μ, where λ is the customer arrival rate, and for the problem to have a non-trivial solution, one must have $\rho < 1$. The unique root of the fundamental equation of the branching process, say r, then becomes the parameter of a geometric distribution for steady-state system sizes at the embedded arrival points [13]. These geometric probabilities are then combined with convolutions of the exponential service distribution to derive the stationary line-delay distribution.

Unfortunately, for the case of Pareto arrivals, a closed form for $A^*(s)$ does not exist. This paper uses a method proposed by Harris and Marchal for finding Coxian distribution fits for arbitrary distribution functions using Laplace transform approximations [16]. It turns out that their technique, which is called as the Transform Matching Method (TMM)) works especially well for distributions defined over the full real line but without all moments. Thus use TMM for $A^*(s)$ and then use Newton's method to solve for the root r.

Once the root is found, the queue and system waiting-time distribution functions can easily be derived for $t \geq 0$ as [14]:

$$W_q(t) = 1 - re^{-\mu(1-r)t} \tag{6}$$

$$W(t) = 1 - e^{-\mu(1-r)t} \tag{7}$$

A close observation of the above queue and system waiting-time distribution functions indicates that they have the same functional form as the *M/M/1* queue except with r replacing . Thus the expected queue waiting time, W_q, and system waiting time, W, can be expressed as follows [14] [13]:

$$W_q = \frac{r}{\mu(1 - r)} \tag{8}$$

$$W = \frac{1}{\mu(1 - r)} \tag{9}$$

III. THE INTERWORKING ARCHITECTURE

To analyze the vertical handoff in a heterogeneous mobile network the architecture illustrated in Fig. 1 is assumed. The primary design consideration of this architecture is that all networks are tightly (or centrally) coupled at the IMS for control signaling, thus session mobility is managed by the IMS at the application layer and terminal mobility is facilitated by Mobile IPv4 (MIPv4) at the network layer. In this architecture, a WiMAX and an UMTS network are interworked via an evolved 3GPP core network architecture. The WiMAX core network is directly connected to the GPRS Gateway Support Node (GGSN) of the visiting UMTS network, assuming that trusted access is offered.

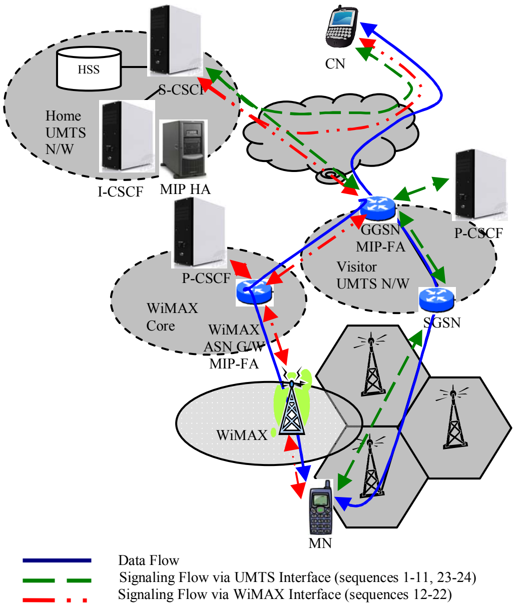


Figure 1. The Interworking Architecture.

The UMTS core network is connected to the all-IP network through the Gateway GPRS Support Node (GGSN), which also acts as its MIP Foreign Agent (FA). Once the system acquisition is done by a Mobile Node (MN) connected to the UMTS network, the next step is to set up a data pipeline. The actual IP address allocation for the MN is initiated by sending the MIP registration request to its Home Agent (HA) via the GGSN (i.e., the MIP-FA). This mechanism is based on the specifications given under [17]. The MN acts as an IMS-SIP client and sends a SIP registration message to its home system through the Proxy-Call Session Control Function (P-CSCF). Once authorized, a suitable Serving-Call Session Control Function (S-CSCF) for the MN is assigned and its subscriber profile is sent to the designated S-CSCF.

After the activation of the PDP context and the service registration, the MN is ready to establish a call session. As illustrated in Fig. 2, the sequence of the SIP session origination procedure can be described as follows. The mobile origination procedure is initiated by a SIP INVITE message sent from the UMTS interface of the source MN. This initial message is forwarded from the P-CSCF to the S-CSCF of the originating network, via the CSCFs of the terminating network, and finally to the destination. This SIP INVITE carries a request to follow the precondition call flow model. This is important because some clients require certain preconditions (that is, QoS levels) to be met before establishing a session.

Once this is done, the MN can start the media/data flow and the session will be in progress (via the UMTS interface). When this MN roams between WiMAX and UMTS systems, inter-system roaming takes place. Generally, the selection of the appropriate network during inter-system roaming is facilitated by an external trigger such as a network selection mechanism/algorithm (this has not been taken into consideration since it is beyond the scope of this paper). Once the new network has been identified the MN undergoes relevant access registration procedures (in this case, the WiMAX network) and AAA procedures. Next, the vertical handoff process is initiated.

In the case of a WiMAX network, the general handoff process may either take place at layer 2 or layer 3. Layer 2 handoff simply changes the air interface attachment point but keeps the IP attachment point unchanged. On the other hand, layer 3 handoff, which is often referred as "macro mobility," changes the IP attachment point of a mobile user. Therefore, during a layer 3 handoff, the MN must be registered and authenticated with the HA every time it moves from the serving BS to the target BS.

Since the proposed architecture is designed for facilitating IP and session mobility, a layer 3 handoff is performed for facilitating inter-system roaming as illustrated in Fig. 2. Once the MN undergoes relevant access registration and AAA procedures the WiMAX interface performs the MIP registration procedures with the ASN Gateway (MIP FA) as explained previously. This is when the ASN Gateway (MIP-FA) forwards this request (via the CSN) to the MIP-HA and the HA assigns the home IP address to the new WiMAX interface. Followed by this the exchanging of a MIP BU message between the MN and the destination for avoiding triangular routing takes place [18].

The next stage is the taking place of the IMS-SIP session handoff procedures. This requires sending a SIP Re-INVITE (with same Call-ID and other identifiers corresponding to the ongoing session) to the destination SIP UAC. Followed by this is a resource/preconditions reservation for the WiMAX interface. Once this is successfully done the new session flow can be initiated. It is important to note that until such time that the new data flow is initiated via the WiMAX interface, the data flow via the UMTS interface remains active. Thus the model follows the make-before-break handoff mechanism as discussed in [19]. Inter-system roaming from WiMAX to UMTS can also take place in a similar manner. Furthermore, since this design is an extension to our WLAN-UMTS-CDMA2000 interworking platform, WiMAX-CDMA2000 roaming can also be accommodated within this architecture in a similar manner.

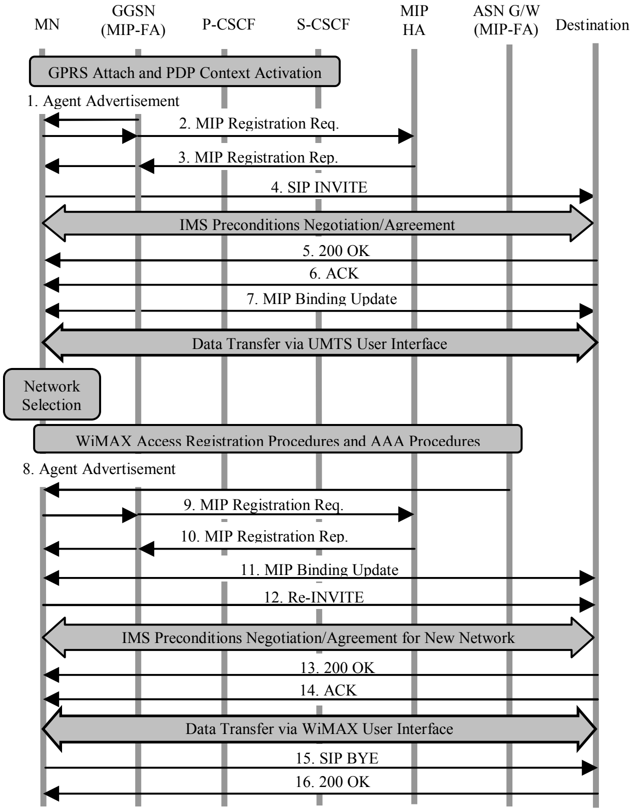


Figure 2. Vertical Handoff Signaling.

IV. VERTICAL SESSION HANDOFF ANALYSIS

An analytical model is derived for evaluating the proposed scheme for analyzing vertical session handoff management for Internet data traffic.

A. *Handoff Delay*

A standard vertical handoff delay during mid-session mobility consists of the following sub-procedures (or delays); D_1 = link layer handoff delay, D_2 = movement detection delay,

D_3 = address allocation delay, D_4 = session re-configuration delay, and D_5 = packet re-transmission delay [20]. The vertical handoff delay at the network layer (and above) are calculated independent of the link layer delay D_1 and mainly consist of D_3 and D_4. According to our proposed architecture for IMS based vertical handoff, there is no Dynamic Host Configuration Protocol (DHCP) related address allocation; hence it can be argued that is D_4 the main contributor for network layer based vertical handoff delay, D. The session re-configuration delay, D_4 mainly consists of the previously mentioned IMS based session negotiation and handoff and Home Subscriber Server (HSS) related message exchange delays.

In order to derive an expression for D, an expression for analyzing the end-to-end transmission delay must be derived. Therefore, if the end-to-end transmission delay for a packet size S sent from network A to network B over a number of hops via wireless and wired links to be expressed as:

$$D(S, H_{a-b}) = D_{wl} + D_w + L_{wl} + L_w \tag{10}$$

where, D_{wl} is the total delay at the wireless interface (say, Base Station - BS), D_w is the total delay at the wired link, L_{wl} is the latency of the wireless link, and L_w is the latency of the wired link. In order to derive D_{wl} and D_w a Pareto/*M/1* queuing model has been applied to the packet flow of the data session at the wireless BS and other networking elements of the IMS on the path of signaling and data routing of Fig. 2.

It is important to note that to apply the results of *Pareto/M/1* analysis, it is assumed that the service times that a packet experiences at different nodes are independent of each other. However, this assumption is untrue, since the service time is proportional to the packet length, and a packet has the same length as it traverses the network. Nevertheless, it has been found that this independence assumption can be used in large networks [15]. Using the results form the *Pareto/M/1* model, expressions for D_{wl} and D_w can be expressed as:

$$D_{wl} = \frac{1}{\mu_{wl}(1 - r_{wl})} \tag{11}$$

where, μ_{wl} is the service rate and r_{wl} is the root of the fundamental branching process equation obtained by solving for z at the wireless interface. For clarity and convenience sake, the units for μ_{wl} are changed from packets/sec to bits/sec. If the probability density function of for packet size, x, in bits be $\mu e^{-\mu x}$ with a mean packet length of $1/\mu$ bits/packet, and the capacity of communication channel i be C_i bits/sec. The product μC_i is then the service rate in packets/sec. Therefore, for channel i, we have:

$$D_{wl} = \frac{1}{\mu C_i (1 - r_{wl})} \tag{12}$$

where, D_{wl} includes both queuing and transmission delays. Also note that the mean packet size does not depend on the channel as the capacity and the input rates do. However, when D_w is considered, it can be expressed as a collection of delays of multiple *Pareto/M/1* queues. It is also assumed that if the output of several *Pareto/M/1* servers feed into the input queue of another server, the resulting input process is also a Pareto process, with mean equal to the sum of the means of the feeding process. This assumption has been derived from a similar assumption made for a *G/M/1* queue in [15]. Thus the total wired network delay experienced by a packet can be expressed as:

$$D_w = \frac{1}{\lambda_w} \sum_j \lambda_j \left(\frac{1}{\mu C_j (1 - r_w)} \right) \tag{13}$$

where, λ_w is the total packet arrival rate to the network, λ_j is the packet arrival rate at j^{th} node, and μC_j is the service rate in packets/sec at the j^{th} node. Thus by combining equations (10), (12) and (13) we get:

$$D(S, H_{a-b}) = \frac{1}{\mu C_i (1 - r_{wl})} + \left\{ \frac{1}{\lambda_w} \sum_j \lambda_j \left(\frac{1}{\mu C_j (1 - r_w)} \right) \right\} + L_{wl} + L_w \tag{14}$$

Now, an expression for the vertical handoff delay D can be expressed by applying (14) to the entire IMS signaling flow involved in the vertical handoff mechanism as illustrated in Fig. 2. Thus the final expression for D is a combination of the following end-to-end delay components as indicated in equation (15).

$$\begin{aligned} D_{IMS} = {} & D(S_{MIPReq}, H_{UMTS\text{-}MIP\text{-}HA}) + D(S_{MIPRep}, H_{UMTS\text{-}MIP\text{-}HA}) \\ & + D(S_{MIP\text{-}BU}, H_{UMTS\text{-}CN}) + D(S_{ReINVITE}, H_{WiMAX\text{-}CN}) \\ & + D(S_{183\text{-}SP}, H_{WiMAX\text{-}CN}) + D(S_{PRACK}, H_{WiMAX\text{-}CN}) \\ & + D(S_{OK}, H_{WiMAX\text{-}CN}) + D(S_{UPDATE}, H_{WiMAX\text{-}CN}) \\ & + D(S_{OK}, H_{WiMAX\text{-}CN}) + D(S_{ACK}, H_{WiMAX\text{-}CN}) \\ & + D(S_{BYE}, H_{UMTS\text{-}CN}) + D(S_{OK}, H_{CN\text{-}UMTS}) + \Delta \end{aligned} \tag{15}$$

where, Δ is the additional IMS (application layer) related latency due to HSS lookup process. The important point to note here is that the derivation of equation (15) has not taken into account the errors that may cause various messages to be damaged or lost. This is since for successful session establishment, the entire message flow must take place and if any message is damaged or lost the vertical handoff process will fail. Hence it has been assumed that the channel is error free during the process of the vertical handoff. It is also worth reminding that make-before-break handoff is applied in the proposed handoff scenarios, which helps compensate for large handoff delays. For the purpose of a complete analysis of vertical handoff delay, the standard straight forward case of break-before-make handoff scenario is used.

B. *Packet Loss*

The total packet loss (*Pkt_loss*) during a vertical session handoff can be defined as the sum of all lost packets during the vertical handoff while the MH is receiving the downlink data packets. It is assumed that the packet loss begins when the layer 2 handoff is detected and all in-flight packets are lost during the vertical handoff time. Thus, it can be expressed as:

$$Pkt\_loss = \left[\frac{1}{2T_{ad}} + D \right] \times \lambda_{wl} \times N_m \qquad (16)$$

where, T_{ad} is the time interval between P-CSCF discovery times, λ_{wl} is the downlink packet arrival rate at the wireless interface, and N_m is the average number of vertical handoffs during a single session [20]. N_m plays a major role in the calculation of packet loss since the packet loss due to vertical handoff is directly proportional to the number of handoffs it is subjected within a given session.

V. NUMERICAL RESULTS

This section presents numerical results relating to the behavior of vertical handoff delay and transient packet loss against system utilization for the case where the shape parameter $\beta = 1.5$. In order to better understand the behavior of the *Pareto/M/1* queue, its performance has been compared against the known closed form values for an *M/M/1* queue. The results used for the performance comparison for an *M/M/1* queue is obtained from one of the authors' previous works on vertical session handoff analysis [21]. Table I provides the typical MIPv4 and SIP message sizes and Fig. 3 provides the relative distances in hops used in the numerical evaluation.

TABLE I. MESSAGE SIZES AND PARAMETER VALUES

Message	**Size (Bytes)**	**Message**	**Size (Bytes)**
INVITE	736	MIP Reg. Req.	60
Re-INVITE	731	MIP Reg. Rep.	56
183 Ses. Pro.	847	MIP BU	66
PRACK	571	MIP BACK	66
200 OK	558	C_i	2-70 Mbps
UPDATE	546	L_{wl}	2ms
ACK	314	L_w	0.5ms
BYE	550	λ_d	33kbps
MIP Agent Ad.	28	T_{ad}	1sec

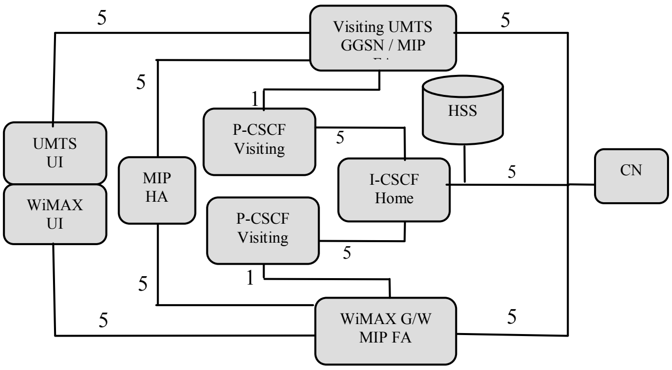


Figure 3. Relative distances in hops.

Fig. 4 illustrates the results for a WiMAX-to-UMTS vertical handoff delay against system utilization for Pareto based session arrivals for different shape parameter values (i.e., β = 1.5, 2.5, 3.5). It also illustrates the results for curve for a Poisson based classical queuing scenario. According to Fig. 4, both results relating to *M/M/1* queuing analysis and *Pareto/M/1* queuing analysis (for β = 2.5 and 3.5) show approximately close behavioral patterns for relatively lower system utilizations (i.e., approximately up to 50%). However, beyond this point, the vertical handoff delay increases according to the nature of the considered packet arrival patterns (i.e., Pareto or Poisson). For example, since Poisson arrivals are relatively smoother and do not show bursty characteristics, the corresponding curve clearly illustrate an exponentially increasing delay. On the other hand, as the system utilization grows beyond 70%, the graphs relating to *Pareto/M/1* queuing model demonstrate signs of heavy tailed behavior.

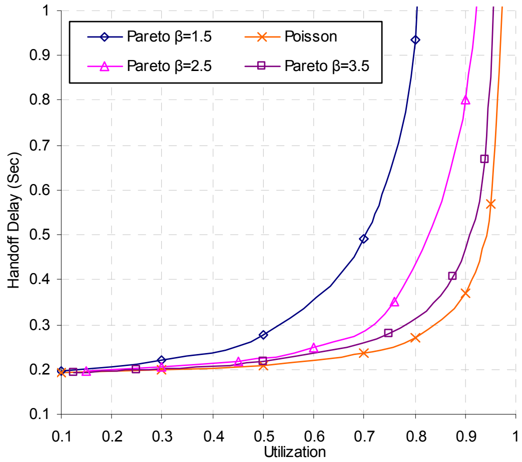


Figure 4. WiMAX-to-UMTS Handoff Delay vs. System Utilization.

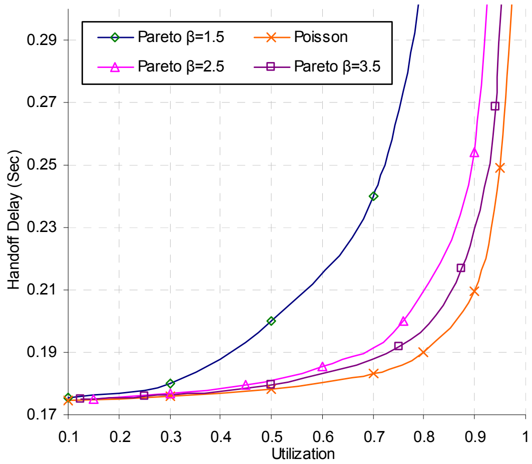
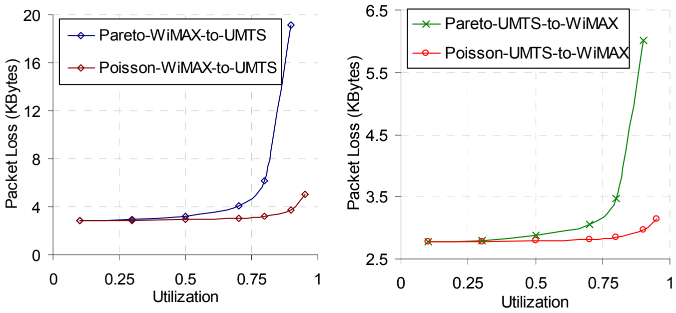


Figure 5. UMTS-to-WiMAX Handoff Delay vs. System Utilization.

Conversely, Fig. 5 illustrates relatively low delays for UMTS-to-WiMAX handoff against utilization. This indicates that when a session is handedoff to a network with a relatively higher link bandwidth, a relatively lower vertical handoff delay may be expected. Also note that for the case of *Pareto/M/1* queue, the long tailed arrivals actually help clear congestion. This is because every once in a while, there are unevenly distributed long inter-arrival times. However, for the case of $\beta = 1.5$, the mean inter-arrival times become finite, which eventually leads to congestion in the system. However as β gets larger, such extreme behavior is not experienced [22].

Fig. 6 illustrates the transient packet loss during vertical handoffs as the system utilization increases for (a) WiMAX-to-UMTS and (b) UMTS-to-WiMAX scenarios. According to equation (16), the packet loss during a vertical handoff is directly proportional to the vertical handoff delay. Therefore, relatively high vertical handoff delays indicated by the WiMAX-to-UMTS graphs in Fig. 4 directly relate to the two high packet loss curves in Fig. 6. Similarly, the packet loss is relatively low in Fig. 6 for a UMTS-to-WiMAX handoff, which is in line with the two relatively low handoff delay graphs shown in Fig. 5. Further, the exponential and heavy-tailed behaviors can also be observed in Fig. 6 for Poisson and Pareto based models respectively.



(a) (b)

Figure 6. Transient Packet Loss vs. System Utilization.

VI. CONCLUSIONS

This paper presented a novel analytical model based on *Pareto/M/1* queuing for evaluating vertical handoffs for a roaming user in a heterogeneous mobile network. Using the proposed analytical model, an in-depth analysis was performed for investigating the vertical session handoff delay from WiMAX-to-UMTS (and vice-versa) against system utilization. The results obtained from the *Pareto/M/1* queuing analysis were then compared against the *M/M/1* classical queuing analysis. According to the results, both queuing methods show approximately close behavioral patterns up to 60% of the system utilization. As the system utilization grows beyond 80%, the *Pareto/M/1* queuing models shows its characteristic heavy tailed behavior.

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