PERFORMANCE EVALUATION AND TRAFFIC ANALYSIS

FOR ROUTING PROTOCOLS IN A REAL MANET

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ABSTRACT

Mobile Ad-hoc NETworks (MANETs) are characterized by bandwidth constrained links, multiple hops, varying link qualities and highly dynamic topologies. In this paper, we evaluate the performance and analyze the traffic of a mobile ad-hoc network in a realistic setting. Using simulation, we provide results of performance evaluation in terms of various metrics. We study performance with scenarios of different propagation matrices, different traffic mixes, and different routing protocols (DSDV, DSR, AODV). The results show that in most cases, the performance is sensitive to the routing protocol, path loss, and traffic characteristics. This provides rationale and insight for choosing the right protocols to provide quality of service in terms of different metrics in different environments. Also we find that in a MANET, we obtain long range dependency traffic regardless of source file size distribution. This discovery will help in providing methodology to tackle the network dimensioning problem in ad hoc networks.

I. INTRODUCTION

A mobile ad-hoc network (MANET) [1] is an autonomous system that consists of mobile nodes communicating with each other via wireless links without a static infrastructure (e.g. base station). These networks are receiving increasing attention in recent years in civilian and military scenarios, thanks to their obvious advantages when establishing networks in resource limited environments, such as exploration and combative operation. The MANET environment is characterized by frequently changing network topology and varying channel conditions. In these circumstances, routing is a very challenging problem. A routing algorithm must be effective to find available routes, efficient to use minimum resources, and resilient to adapt quickly to link errors and topology changes. Many different routing protocols have been proposed. In this research we investigated three of most widely implemented and studied protocols: DSDV [2], AODV [3], and DSR [4].

It is important to understand the performance of different routing protocols, and some relevant work that has been done in the past few years [5], [6], etc. The limitations of these studies are: 1) they only use random waypoint model for simulation which does not capture real world mobility; and/or 2) they use constant bit rate traffic which does not reflect the complex nature of traffic in real applications. The relationship between traffic and routing is well worth investigation. This paper evaluates the performance of various routing protocols with various traffic patterns and traffic mixes in a MANET. The mobility pattern and path losses were obtained from a real life exercise. We also present simulations of the routing protocols with a realistic traffic under random waypoint mobility. The results presented in this paper can be used to dynamically choose a routing protocol based on traffic patterns, path losses and performance metrics that are important.

The rest of the paper is organized as follows. First, we will describe in detail our simulation model. Then, we present simulation results on performance metrics for the different routing protocols in various environments. In section IV, we present the simulations of the three protocols under random waypoint mobility. Then, we present traffic analysis for a MANET in various traffic settings and under various routing protocols. Conclusions are presented in the last section.

II. SCENARIO SETUP

This work provides a simulation-based study on MANET traffic characteristics and performance evaluation of different routing protocols in a realistic scenario. We consider

the mobility pattern of a troop, which consists of 43 mobile nodes (including vehicles and soldiers), obtained from a real military exercise. All the nodes are treated identically. The movement is within a rectangular region of dimensions $6km \times 8km$. The initial position of the troop is at the southeast corner of the area, and the troop is moving forward in the direction towards the northwest at the average speed of 0.7m/s. The propagation matrix is obtained from ITM (Irregular Terrain Modeler), which specifies the node-to-node propagation path loss at different time instances. In our scenario, the propagation matrix is symmetric indicating symmetry in node-to-node path loss.

The traffic in the MANET consists of voice communications (such as commands and reports by voice), video streaming (such as realtime battlefield reconnaissance), and file transfer (such as map downloading). The traffic generation at a node is modeled as a Markov process for different types of transmission. Voice traffic (UDP) is modeled by an exponentially distributed ON/OFF process with 8kbps transmission rate during the ON period. Video traffic (UDP) is modeled by an MPEG traffic model, in which the "I" frames are generated by an auto-regressive model; "P" frames and "B" frames are both lognormal random variables. File transfer traffic is sent by FTP on TCP NewReno, with finite file size distributed as a Pareto random variable with parameter 1.5; the TCP data packet size is fixed at 1460 bytes and the file size averages at 50 packets. We allow multiple connections simultaneously initiated from the same node. In this paper, we refer to the file transfer traffic as FTP traffic. The terms FTP traffic and TCP traffic are used interchangeably. The parameters of traffic are set based on the requirement that all the three types of traffic impose equal load on the network. We will later change these parameters so as to study the effects of nonclassical traffic on the network performance. All types of traffic are modeled in a way that efficiently approximates real traffic, for example, the Pareto distribution of FTP traffic has been reported in Internet and LAN environment.

The simulator tool we use in this work is *ns2* with *monarch* extension for mobile network. We use IEEE 802.11 as our MAC layer protocol using Distributed Coordination Function (DCF) to handle contention. The physical layer uses designated propagation matrix as fading model, implemented by us in *ns2* using C++. Accept/drop policy in *monarch* is a hard-limited function. In the simulation, all nodes have only one wireless network interface, so they share a single channel. The bandwidth of the shared medium is 2Mbps, and the interface queue at each node buffers up to 50 packets in a drop-tail fashion.

III. PERFORMANCE COMPARISON

In the simulations, we focus on the following three metrics:
- *Average end-to-end delay:* Average delay experienced by the data packets.
- *Packet loss:* The difference between the number of packets received and packets sent over the number of packets sent, measured in percentage.
- *Goodput:* the percentage of data traffic in packets over total traffic, including data traffic and routing traffic. In multihop case, routing packets transmitted at each hop counts as one. So larger the number of hops, smaller the goodput is.
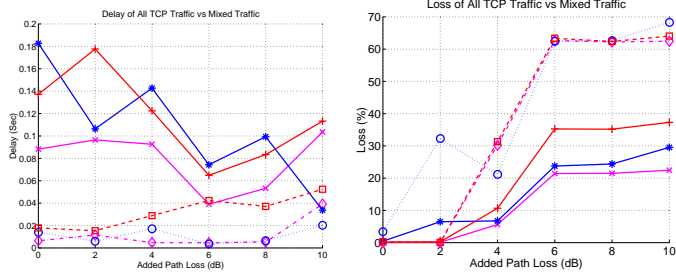
End-to-end delay is an important metric in delay-sensitive applications, which require realtime delivery, such as voice traffic and critical messages. Packet loss is the result of partitioning due to heavy path loss, congestion due to traffic condition, and route availability due to mobility pattern. Packet loss results in poor quality and/or large latency in communications. Goodput relates to the efficiency and scalability of routing protocols. It is important since in real scenario there are large number of power-limited mobile agents.

To emulate inclement communication environments, such as foliage or precipitation, we increment path losses in the propagation matrix uniformly for all links in each simulation. This stress test will cause the number of hops required for successful transmission to increase. This will illustrate how different routing protocols will behave as the number of intermediate hops increase.
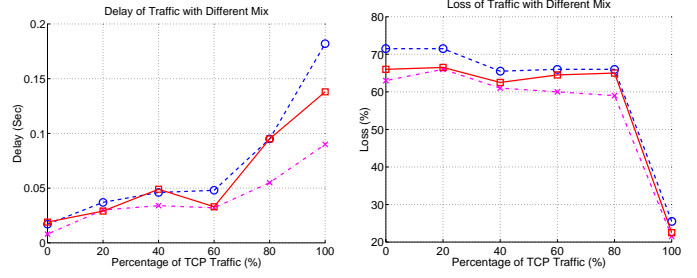
A. DELAY

We performed the simulations for a time duration of 5 min for each case, run each case for 3 times for different realizations of the same traffic pattern distribution, and took average for interested statistics. For each traffic pattern, the statistics are collected for 0dB (original), 2dB, 4dB, 6dB, 8dB, and 10dB added path loss in the propagation matrix. Figure 1(a) compares the average delay experienced by all data packets when 1) the nodes generate mixed (a mixture of voice, video and FTP) traffic and 2) the nodes generate only FTP traffic. In each of these cases, the total traffic load is the same (5 kbps).

Figure 2(a) shows the scenarios with gradually incremented FTP traffic percentage. It is interesting to see from Figure 1(a) that the relative delay performances of different routing protocols depend on the traffic mix. For mixed traffic that has small amount of FTP transmission, AODV has the largest delay. In certain propagation path loss settings, the average AODV delay can be four times as large as that of DSDV and DSR (Figure 1(a) at 6dB
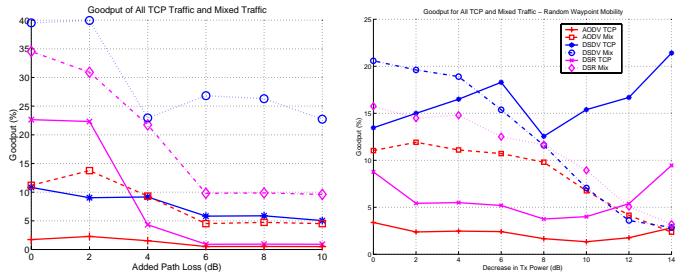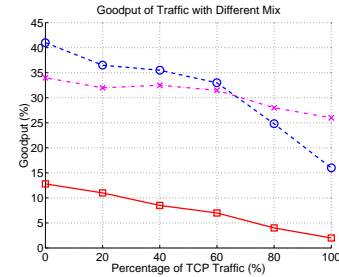
(a) Delay   (b) Loss

(c) Goodput   (d) Goodput: Random Way-point Mobility

Figure 1. Comparison of Total Packets of All TCP and Mixed Traffic (DSR TCP - "x" Marked, DSR Mix - "diamond" Marked, DSDV TCP - "*" Marked, DSDV Mix - "o" Marked, AODV TCP - "+" Marked, AODV Mix - "square" Marked)

(a) Delay, No Added Path Loss   (b) Loss, 10dB Added Path Loss

(c) Goodput, 0 Added Path Loss

Figure 2. Comparison of Total Packets in Different Traffic Mix (DSR - "x" Marked, DSDV - "o" Marked, AODV - "square" Marked)

added path loss). We can also observe that large proportion of FTP traffic in total traffic brings large average delay (Figure 1(a) and Figure 2(a)). The larger average delay in the case of FTP traffic can be explained by the TCP retransmission and congestion control mechanisms. But from Figure 2(a) it is clear that differences in delay among different protocols with no additional path loss become significant only when the percentage of FTP flows is larger than 60%. So the switching point of the percentage of TCP mix, after which different protocols have different delay performance, depends on the path loss.

B. PACKET LOSS

Figure 1(b) compares loss percentage of total traffic when we use both mixed traffic and all TCP traffic in various path loss settings. Figure 2(b) describes loss performance for different percentage of TCP transmission (FTP traffic) in the total traffic. It seems quite surprising that the more TCP traffic, the less the loss of packets (Figure 1(b) and Figure 2(b)). All three protocols have similar performance over the loss metric, while DSDV is slightly worse compared to the the other two (Figure 1(b) and Figure 2(b)). A possible explanation is that since the size of TCP packet is larger than that of voice and video packet and we

maintain total traffic load in bytes, larger portion of TCP traffic means smaller number of packets transmitted. Hence loss percentage is more affected by the number of packets transmitted than the size of transmission in bytes.

C. GOODPUT

We show goodput for mixed traffic and all the TCP traffic (FTP traffic) for different path loss settings in Figure 1(c). In Figure 2(c) goodput performance is shown scenarios with gradually increasing TCP traffic mix. The observations are: 1) DSDV gives best goodput in most scenarios and AODV gives the worst, but in low path loss and high TCP traffic mix case DSR gives the best performance in term of goodput. DSR is the least robust in goodput when the path loss is changed (Figure 1(c) and Figure 2(c)); 2) goodput deteriorates when path loss increases (Figure 1(c)) and proportion of TCP traffic increases (Figures 2(c)). It should also be noted that the goodput performance gap between different protocols are very large: for example, in all TCP traffic case where we use the original propagation matrix, goodput of DSDV is 70% but goodput of AODV is strikingly only 11% (Figure 1(c)). So in terms of effectively using available bandwidth to transmit desired information, selecting the right routing protocol is crucial.

Observation 1 can be explained as follows: The number

of hops between source and destination increases when path loss increases. The routing overhead in DSDV is less sensitive to the number of hops required for transmission, compared to on-demand routing protocols, such as AODV and DSR, which require lots of *Route Request*, *Route Reply* and *Route Error* messages to discover and maintain routes. Larger number of routing messages gives lower goodput performance. Goodput performance of DSR against path loss is linked to usefulness of source routing and route caching in different environment. Observation 2 can be explained as follows: The low goodput for the TCP traffic is due to retransmissions, the total number of data packets transmitted for the successful reception of a single data packet increases. The low goodput of the reactive routing protocols AODV and DSR versus that of the proactive routing protocol DSDV in this mobility pattern is due to the very small relative mobility of the nodes.

IV. **RANDOM WAYPOINT MODEL**

In this section, we describe simulations of AODV, DSR and DSDV routing protocols with the underlying node mobility model being the "Random Waypoint Model" [5]. Under this mobility model, a node selects a random destination within the area of mobility and moves with a random speed $v(0 < v <= V_{max})$ towards the destination. After reaching the destination, the node pauses for a random time p and continues motion towards the next destination. The random waypoint model has been extensively used for simulations to evaluate the performance of protocols in ad-hoc networking. In our simulations, we chose $V_{max} = 1.4 m/s$ and zero pause time. We performed simulations with FTP only traffic and a mix of voice, video and FTP traffic as described in section II. The area of movement was chosen to be a rectangular grid of $3756m \times 1225m$ corresponding to the area of motion of the soldiers as described in section II. The number of mobile nodes was set to 43 as mentioned in section II. The transmit power is initially set to 3.67W and is reduced in steps of 2dB. The reason for studying varying transmit power is to simulate the environment with different SNR levels, equivalently different path losses. Figure 1(d) shows the goodput observed with different routing protocols in this case. It can be seen that DSDV has the highest goodput followed by DSR followed by DSDV. Goodput has the number of hops as a term in the denominator. DSDV calculates shortest paths; thus contributing towards its high goodput. Route caching in DSR can explain for its higher goodput in the case of high transmit power. It can also be seen that the goodput is higher for the mixed traffic cases as compared to FTP only (TCP only) traffic cases. For all the three routing protocols, the mixed traffic case is sensitive to decreases in transmit power. It is interesting to see that the goodput for the FTP only (TCP only) traffic is not sensitive towards reduction of transmit power.

V. **TRAFFIC ANALYSIS OF AD HOC NETWORK**

Here we analyze and compare the traffic behavior in the mobile ad-hoc network scenario with different routing protocols. Traffic behavior is one of the key factors for the performance evaluation in a network. It is well known that the heavy-tailed distribution of file size causes a self-similar traffic in wireline networks [7], which in turn has profound implications for network performance. However, the impact of file size distribution to the traffic behavior is still not clear in the wireless environment. In order to investigate the impact of file size distribution, we generated file sizes with Pareto and Exponential distribution respectively and transmited the files by FTP. The traffic is driven by the TCP mechanism and routing protocol in the network simulator. We employed wavelet analysis [8] to analyze the traffic and estimated the $Hurst$ parameter of self-similarity.

Let X_i be the number of bytes transmitted every $1\ msec$ and $d_{j,k}$ be the detail coefficient of the discrete wavelet transform of process X_i [9]. A process X_i is called (asymptotically second-order) self-similar with $Hurst$ parameter H if it satisfies

$$Var(X_i^{(m)}) = \frac{Var(X_1)}{m^{2-2H}}, \quad as\ m \to \infty \qquad (1)$$

$$R_{X^{(m)}}(k) \to R_X(k), \quad as\ k \to \infty \qquad (2)$$

where $X_i^{(m)} := \frac{1}{m}\sum_{i=1}^{m} X_i$. On the other hand, we say a stationary finite-variance process X_i displays long range dependence (LRD) if its auto-covariance function $r(k) \sim ck^{\alpha-1}$ as $k \to \infty$. It can be shown [10] that $\alpha = 2H - 1$.

Based on the property of wavelet decomposition, it can be shown that the wavelet transform of a self-similar process X_i has the following property [11]:

$$log_2 E[d_{j,.}^2] \approx j\alpha + log_2 C(\alpha, \psi_0), \qquad (3)$$

where $C(\alpha, \psi_0)$ is a function of the wavelet ψ and α. Since $C(\alpha, \psi_0)$ is independent of j, the slope of this Log-scale diagram provides a good estimator to the LRD parameter α (and H). We show the Log-scale diagram of traffic with different routing protocols in Figure 3. We estimated the similarity parameter of the traffic by Arby's method [8].

In the scenario of the previous section, the file size has a Pareto distribution with shape parameter 1.5. We compare the Log-scale diagram of the traffic under different routing protocols AODV, DSDV and DSR. Since the routing protocol generates control packets, the mean traffic rate observed in the network is dependent on the routing protocol, as shown in Table 1. However, the Log-scale diagram in Figure 3 has a nonzero slope for every experiment, which indicates

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Protocol & File Distri.	Mean (KB/sec)	H
AODV-Pareto	18.8783	0.8230
AODV-Exp	14.2935	0.9080
DSDV-Pareto	18.4647	0.8350
DSDV-Exp	13.7245	0.9520
DSR-Pareto	30.0153	0.8720
DSR-Exp	27.9220	0.9210

Table 1. Mean Transmission Rate and Hurst Parameter

that the traffic has long range dependency. It is interesting to investigate if this phenomenon is caused by the file size distribution or not. To answer this question, we replaced the Pareto distribution by the Exponential distribution and repeated the experiments. The analysis results show that the new traffic still has long range dependency when the time scale is less than 8 seconds (octave $j < 13$). This result implies that the network mechanism causes a self-similar traffic at a time scale less than 8 second. We suspect that the reason for this phenomenon is due to some characteristics of ad-hoc routing protocols, which need thorough investigation.
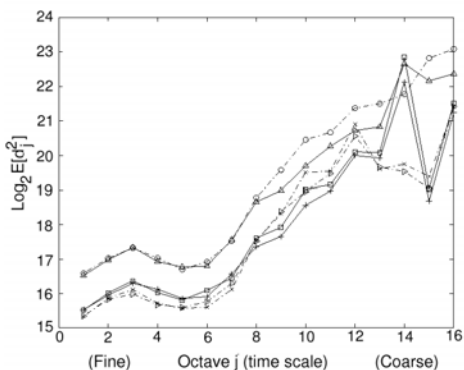

Figure 3. Log-scale Diagram (slope α is estimated between j=6 and 12) (AODV Pareto - "+" Marked, AODV Exp - "right triangle" Mared, DSDV Pareto - "square" Marked, DSDV Exp - "x" Marked, DSR Pareto - "triangle" Marked, DSR Exp - "o" Marked)

VI. CONCLUSION

Our work in MANET routing protocol evaluation and traffic analysis is novel in the sense that we use real-life scenarios. We have seen that DSDV performs well in end-to-end delay and goodput, but suffers slightly compared to the other two routing protocols in packet loss. Since the mobility is small, AODV has lesser goodput compared to DSDV, and in some scenarios we studied gives larger end-to-end delay as compared with DSDV. DSR's performance on goodput is not robust to path loss. All the protocols are in some scenarios sensitive to nonclassical behavior of transmitted traffic.

One discovery that we believe is being reported for the first time is that MANET traffic possesses some kind of innate behavior of long range dependency regardless of TCP file size distribution. This is important because long range dependency, which prevails in Internet and Ethernet traffic, has very different properties from classical types of traffic. We can utilize analysis tools for traffic from Internet and Ethernet to do correct dimensioning for MANET.

Future work will be focused on the following directions. Firstly, a more comprehensive study that includes more MANET routing protocols will be performed. We also intend to find a "switching curve" that helps to decide in real situations which routing protocol is best suited for the requirements of given environmental and traffic conditions. That will give us a policy to dynamically select routing protocols. Secondly, we will continue our study of traffic characteristics in MANET and try to build a theoretic model to explain and emulate real MANET traffic.

STATEMENT

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