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Technical Report No. TR_2007-3

June 2007

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ABSTRACT

In this paper, we present our observations and analysis of traffic patterns, loss behavior, throughput analysis and delay behavior of an emergency response network which could be implemented very quickly and efficiently in disaster-affected areas. We collected the audio, video, broadcast packet data of various durations on fixed end-nodes and relay-nodes. We analyze and present our observation results in terms of traffic volume, throughput analysis, loss and delay behavior. As expected, a significant amount of packet loss in long delay and narrow satellite channel was apparent. From the data collected, it was noticeable that the loss becomes more severe with bursty behavior of the traffic. We show an analysis of throughput of the network, including per flow and per hop basis. The result suggests that we should not use more than three hops for any multimedia communications over a MANET and satellite channel.

1. INTRODUCTION

DUMBONET [2] is designed to provide a reliable communication infrastructure in emergency situations. We assume a number of isolated disaster affected sites (for example, different sea shore area affected by tsunami) comprises a local area mobile ad hoc network (MANET) and a distant command headquarter as shown in Figure-1. A headquarter is considered as a special site having the privilege of talking to every sites on the net and sometimes broadcast messages to all sites. A disaster site of DUMBONET can maintain a communication channel with headquarter while possibly opening up communication channels with other selected peering sites on the net based on demand. At each disaster site, as traditional communication infrastructure is no longer available, we shall bring in mobile devices capable of creating a self-organizing, self-resilient mobile ad-hoc network (MANET) that permits multimedia communication among the devices. We also need to provide multimedia communication among different sites and with different rescuer team and command headquarter. Having multimedia internet capabilities allows rescuers to collaborate more effectively by sending and receiving rich and crucial multimedia information. Rescuers may also consult with case experts through the Internet to gain knowledge necessary for the operation.

A highly practical choice to link up widely distributed disaster sites is to deploy satellite access which can restore connectivity in a relatively short amount of time but it has a high propagation delay. Our main challenge is to create a single networking domain called DUMBONET that enables effective multimedia communication among the disaster-affected sites and with the command headquarter. DUMBONET consists of heterogeneous networks having different MANET devices, various link types (i.e. WiFi, satellite, and terrestrial) with very different link characteristics (i.e. bandwidth, packet loss pattern, and delay.)

In a heterogeneous network like DUMBONET, the overall performance could depend on many areas including link layer inter-operability of different nodes and channel, frequent routing table updates when a network topology is changes because of mobile nodes, managing a congested or bottleneck link efficiently, selecting bandwidth-adaptive audio or video codec to enhance application-level performance etc. One of the main challenges of this network is to provide a framework integrating all the

heterogeneous devices and moreover provide a collaborative multimedia supported application for a very easy and efficient disaster management system. Out objective is to identify the possible problems and challenges of the network and to provide a stable and fined-tuned communication system for a quick emergency response in disaster recovery.

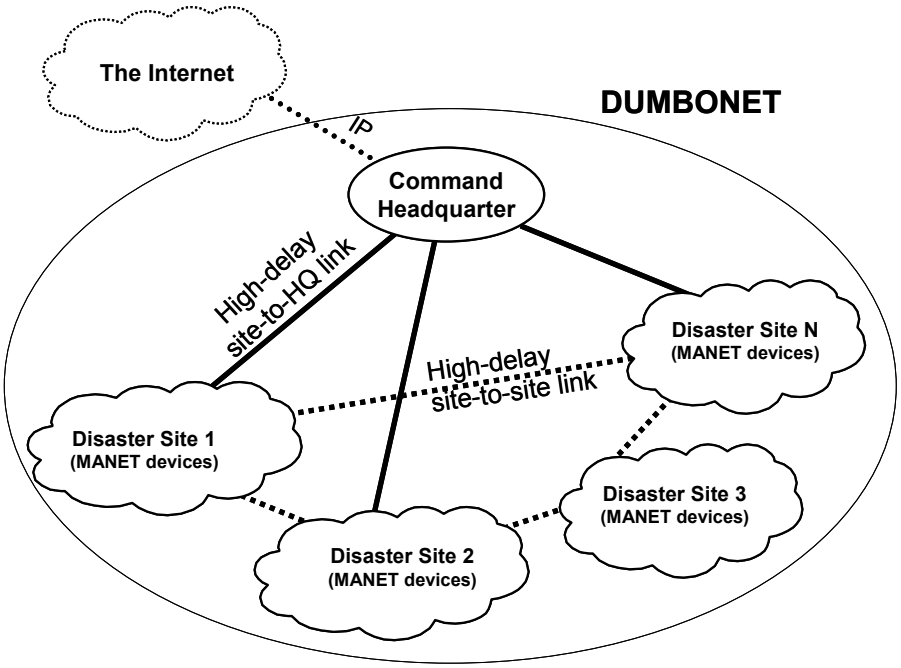

Figure-1: DUMBONET Architecture
Source: Kanchana et al. [2]

This paper concerned with the evaluation results of DUMBONET with the various performance measurements and analysis. We present the performance behavior and analysis which was derived from real fieldwork and literature studies. This research is the part of DUMBO project [3]. The overall aim of DUMBO is to propose a network and software architecture for emergency response operations in disaster-affected areas to overcome the various challenges like quick establishments of a communication system for first responders and disaster management workers, sharing and dissemination of information etc. [5, 2, 4]. The rest of the paper is organized as below. Section 2 discusses our environments which includes the experimental test-bed, the network topology and our measurement tool description. Section 3 contains the measurement results where section 4 presents analysis and discussions of the measurement data collected. Related works are presented in section 5 where a conclusion of the paper is presented in section 6.

2. MEASUREMENT ENVIRONMENT

2.1 Test-Bed Topology

The experimental network topology is shown in Figure-2. We can divide our whole network in three subparts where two of them are complete MANET emulated as disaster-affected areas (site1 and site2) and other one is called “AIT Network” shown in the middle which is emulated as disaster management headquarter.

To form a MANET, every mobile device is set to use the adhoc (peer-to-peer) WiFi mode and to run the Optimized Link State Routing (OLSR) protocol [7]. OLSR is a link state routing protocol, analogous to OSPF and relies on knowledge of complete topology information at all nodes. The OLSR protocol uses

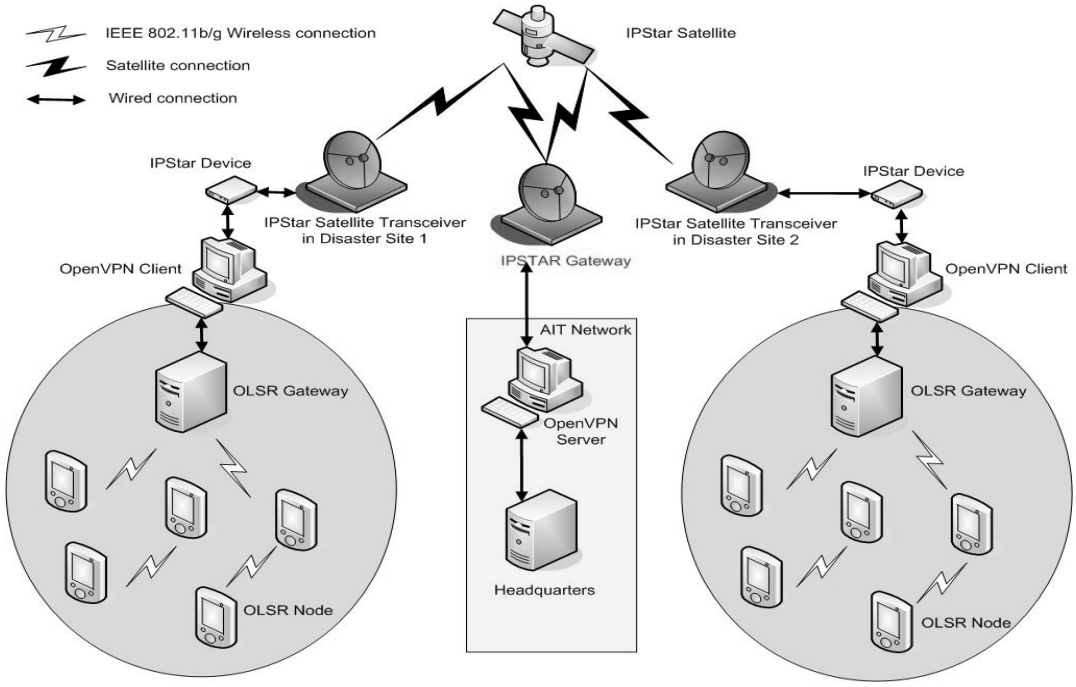

Figure-2: Experimental topology of DUMBONET

a special mechanism called Multi-Point Relay (MPR) to reduce the number of flooded messages. We used OLSR v0.4.0 implementation from UniK [6] in our all the devices. Every mobile device is set to use the ad-hoc (peer-to-peer) WiFi mode and used the BSSID named "DUMBO". Static IPv4 address from subnet 192.168.1.0 has been assigned to each laptops, desktops and PDA. To remove the ambiguity of identifying a node in which disaster site, we maintained some criteria during assigning an IP address to a node. All the nodes in disaster site 1 were assigned with IP addresses pool below 100 and other site was assigned with IP addresses above 100. The network in headquarter were assigned with IPs above 200.

Table-1: The description of computers and mobile nodes used in DUMBONET

Device	Interfaces	CPU	interface	RAM	OS, Tools
NOKIA 770 PDA	Conexant 3110 Chipset 802.11b	ARM 240 MHz	2 Mbps	64 MB	Debian Linux, tcpdump
HP Laptop	Intel 945 802.11b/g and Intel Pro/100 VE	Intel Dual core 1.73 GHz	2-11 Mbps 100 mbps	512 MB	Windows XP, EasyDC, Ethereal
Asus Laptop	Atheros 802.11b/g	Celeron 1.66 GHz	2-11 Mbps	512 MB	Windows XP, EasyDC, Ethereal
Desktop	Realtek RTL-8139	Intel P4 3 GHz	100 mbps	512 MB	Windows XP, EasyDC, Ethereal

Each MANET communicates with each other using a geostationary satellite, known as IPStar [8] with ku-band satellite symmetric channels with 500 kbps bandwidth from site1 to site2 and 300 kbps bandwidth from site2 to site1. Any traffic from a site's transceiver to headquarter goes to IPSTAR gateway using satellite channel, then from IPSTAR gateway to AIT Network using terrestrial network, or vice-versa. The IPSTAR architectural design makes all the communication from any IPSTAR transceiver (ground station) is routed through IPSTAR gateway (ground station) as shown in Figure-2. As a result,

the communication from a transceiver to traditional Internet requires 1-hop satellite communication. And, the communication between two transceivers requires 2-hop satellite communication. IPSTAR has mobile satellite transceiver which allows us quick (within a few hours time) restore of internet connectivity in the disaster affected areas, proved extremely beneficial to the search and rescue operation where traditional terrestrial communication infrastructure is severely disabled.

In our test-bed, we use virtual private network (VPN) to hide network heterogeneity that arises from the use of different networking technologies consisting of satellite, MANET, and terrestrial internet. We used the software named OpenVPN [9]. From the perspective of mobile devices, they belong to the same private IPv4 subnet (e.g. 192.168.1.0) that spans across all different geographical locations (i.e. headquarter and disaster-affected sites). At the present, we only use the OLSR protocol to route traffic among the devices that may not have direct wireless contact but are located within the same foresaid private IP subnet. The OLSR protocol also has additional routing capabilities, such as Host Network Association (HNA), that we have not used. Another reason to use VPN is to route the OLSR control packets over the satellite channels. We wanted to see the behavior of OLSR control packets over a long delay link. Thus, the entire DUMBONET worked as a single OLSR network that includes local MANETs, and inter-site links through VPN and satellite.

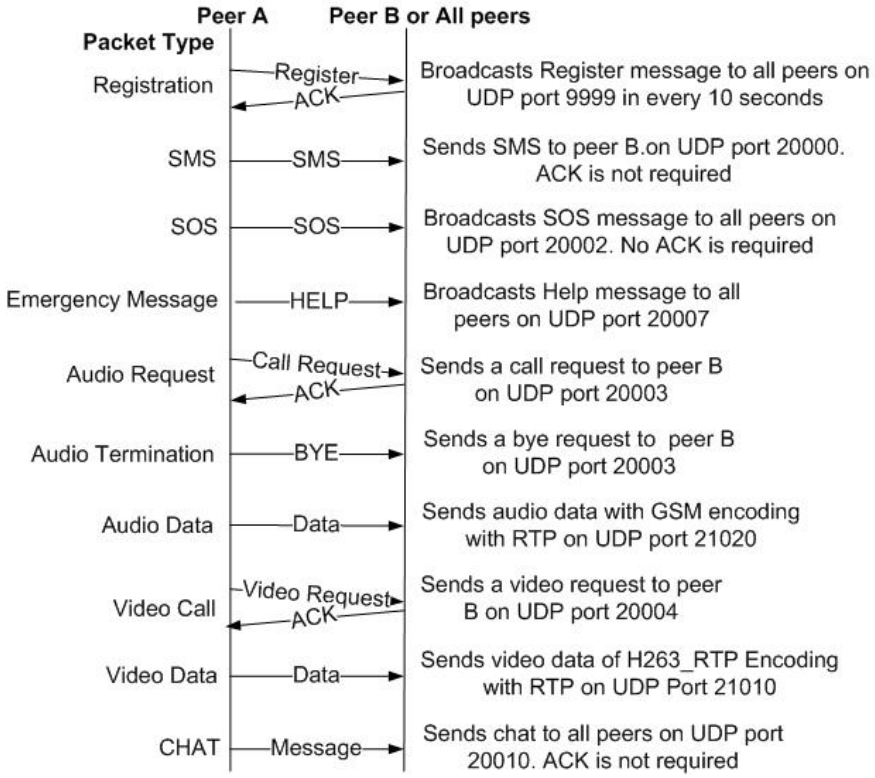

Figure-3: Different types of messages in EasyDC showing the different types of EasyDC packets exchanged between two or more peer nodes and the ports they use

We used 8 laptops in site1 including the OLSR gateway and OpenVPN client installed in one laptop. In site2, we have used 4 laptops and 4 PDAs including the OLSR gateway and OpenVPN client in one laptop. At the other side, in AIT network, a desktop computer was running "Easy Disaster Communication" (EasyDC) [1] (headquarter version) and another desktop computer was running OpenVPN server. The description of used computers and mobile nodes are given in Table-1. In site1 and

site2 of DUMBONET, some laptops were used as end nodes and use EasyDC in the disaster area while some other laptops and PDAs were used to relay the traffic to another node in a multi-hop network.

2.2 Experimental Tools

To provide the multimedia capable communication among different rescue teams and headquarter, we developed an application named "Easy Disaster Communication" (EasyDC) [1]. The application was developed with Java. The application uses UDP protocol to provide one-to-one communication with short messages (SMS), text-based chat channels, voice call, video communication as well as one-to-many send-to-all communication between a pair of users. For the audio and video communication, the application uses RTP protocol to track the packet orders. The application level messages and their exchanges are shown in Figure-3 and Figure-4. The application has both client and server side capabilities hence working as peer-to-peer software.

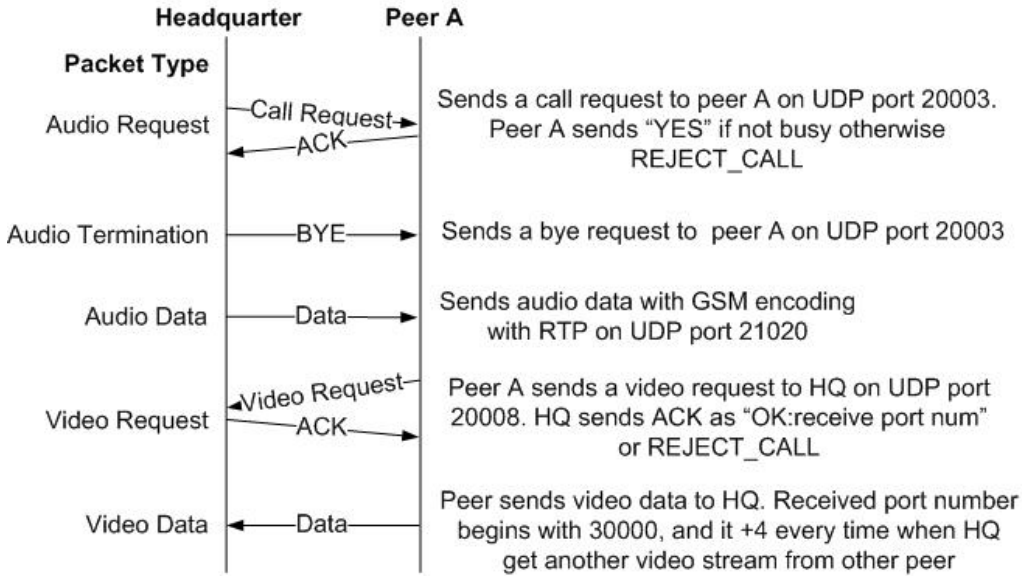

Figure-4: Different types of messages in EasyDC headquarter showing the different types of EasyDC packets exchanged between two or more peer nodes and the ports they use

However, the limitations were more control overhead, cache stall, and scalability problems which are explained in more details in the sections below. Since each node periodically broadcasted its user information at application layer, this broadcast caused more extra overhead into the MANET. Table-2 shows the traffic bandwidth consumption for different types of communication in EasyDC. It is clearly seen that bandwidth occupied by a video communication is much higher compared to the bandwidth occupied by chat messages or emergency broadcast messages. In that case, if we do not have enough bandwidth to run the video or audio, we still have chance to give or receive commands by text-based chat channel or broadcast messages.

3. MEASUREMENT RESULTS

Our experiment was basically divided into two parts where in the first or part I, we setup our experimental test-bed within the campus of the Asian Institute of Technology (AIT), Thailand. We set up one IPSTAR transceiver in front of the intERLab office in AIT with the OLSR gateway in intERLab creating the MANET site1. Another IPSTAR transceiver was set up at another end of the campus in front of the DEC office with the OLSR gateway in DEC creating the MANET site2. The test-bed was on from

13th November to 18th November. In these experiments, we used human being to carry the laptops all over the AIT campus emulating mobile nodes to create multi-hop MANET.

Once the OLSR was working properly to create the MANET and VPN was working properly to connect all the sites together, we used the EasyDC to do our desired experiments. The network traffic overview is shown in Table-2. At first, end nodes with EasyDC registered themselves with a name and all the nodes running EasyDC exchanged the register messages by themselves. A node made an audio call to another node or sent live video stream to another node only when they saw each other registered in the peer-to-peer network. The audio and video call durations varies ranging from 5 seconds to 250 seconds. We captured the traffic at both the sender and receiver ends in all cases using Ethereal (a.k.a. Wireshark), and using Tcpdump in PDAs. The measurements was carried out over several days where we collected more than 50 trace files consisting 0.65 million packets and a total duration of more than 2400 minutes.

Table-2: Traffic overview in DUMBONET

Packet Type	Packet Size (bytes)	Frequency (packet/sec)	Bitrate (kbps)
OLSR Hello	60	≤ 1	0.47
OLSR TC	56	≤ 1	0.44
EasyDC Broadcast	60	≤ 1	0.47
EasyDC Chat	60 – 1470	≤ 1	0.47– 11.48
EasyDC Audio (GSM)	139	16.67	18.11
EasyDC Video (H263)	60 – 1279	variable	≥ 80

For part II, we setup our experimental test-bed in Phuket, Thailand. We setup one IPSTAR transceiver at the Kinnery Elephant Camp creating the MANET site1. We setup another IPSTAR transceiver at the Phuket Elephant Camp creating the MANET site2. The test-bed was operational from 25th November to 1st December. In these experiments, we used human being spreading all over the camp and emulating end nodes while used elephant to carry our laptops or PDAs emulating mobile relay nodes to create multi-hop MANET.

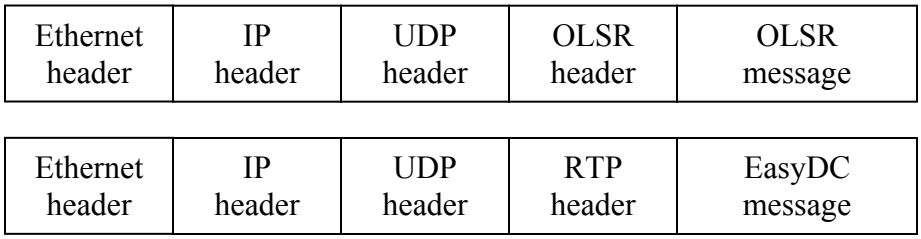

Figure-5: Packet header hierarchies for OLSR messages (top) and EasyDC messages (bottom)

To extract our desired data from the collected trace files, at first, we converted the traces from ethereal trace format to simple text file format with all the packets expanded including the packet data. Then we wrote a parsing and analyzing tool in Java to parse and analyze the trace files. From every trace file, we extracted the packet types (e.g. arp, icmp, udp, tcp etc.) and their counts to calculate the percentage of different types of packet. Then, from all the UDP type packets, we separated all the packets using port 698 which is used by OLSR protocol and all the packets using ports shown in Figure-3 and Figure-4 above to extract the packets generated from EasyDC. By this way, we calculated the percentage of different types of UDP packet. The packet header hierarchies for OLSR packets and EasyDC packets are shown in Figure-5.

To extract the flow information generated by EasyDC, from each UDP type packet, we extracted the source IP and destination IP from IP header, source port and destination port from UDP header. Then we extracted the RTP sequence number from the RTP header. For each quadruple of source IP, destination IP, source port and destination port, we could calculate the loss rate by identifying missing sequence numbers. We calculated the audio or video call duration of a flow, from the time difference of first and last packet received. We calculated the throughput over time for each flow from the RTP payload size. One OLSR packet may contain one or more OLSR messages (e.g. TC, HELLO, HNA, MID type message). From each TC message, we extracted the hop count from the message originator to the receiving node (end node) in the DUMBONET.

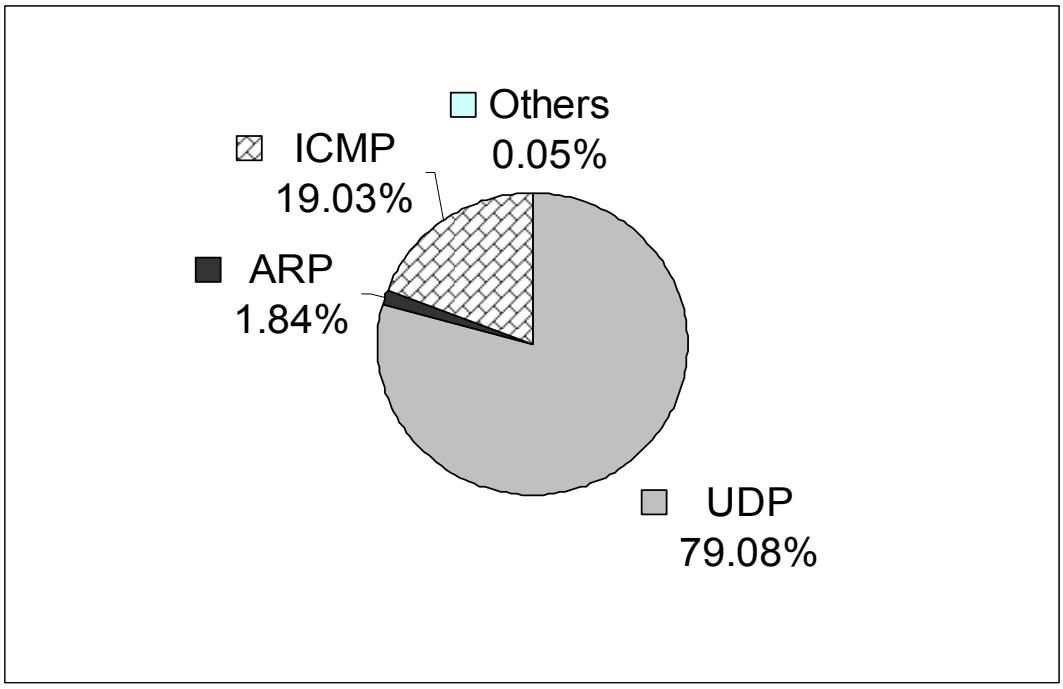

Figure-6: Percentage of different layer traffics from all the traces collected during the whole experimental periods in DUMBONET

We also used the Iperf tool [10] to measure the overall available bandwidth and throughput. Using Iperf, we sent UDP traffic from site-to-site over the satellite in different bitrates like 30 kbps, 50 kbps, 100 kbps, and 200 kbps. For each bitrate, we collected three trace results. Then from the iperf client report, we calculated the end-to-end average throughput for each sample bitrate. We used ping collecting round-trip times (RTT) from a source node to another node to measure the delay behavior in the network. We collected ping data in every 5 minutes interval from one disaster site to headquarter and also from one node to another node within a MANET.

4. ANALYSIS AND DISCUSSION

In this section, we evaluated the application level performance of DUMBONET. We tried to evaluate in various perspectives including the overall traffic volumes, percentage of different types of packet sharing our network, packet loss behavior for different types of traffic, aggressive behavior of dynamic bandwidth traffics like video, throughput analysis per hop basis, and delay behavior. Our findings are shown in the following sections.

4.1 Traffic Volumes

From all the traces collected in many nodes during the whole experiment times periods, we calculated the total number of traffics in different layer. Then we calculated the percentage of different layer traffics which is shown in Figure-6. It is seen that our whole network is completely dominated by UDP traffics which is almost 79% traffics. These UDP packets consists of our OLSR, and all application level traffic like audio, video, chat, broadcast etc. We also see around 2% ARP packets or which was generated if node is out of range with other nodes wireless frequency.

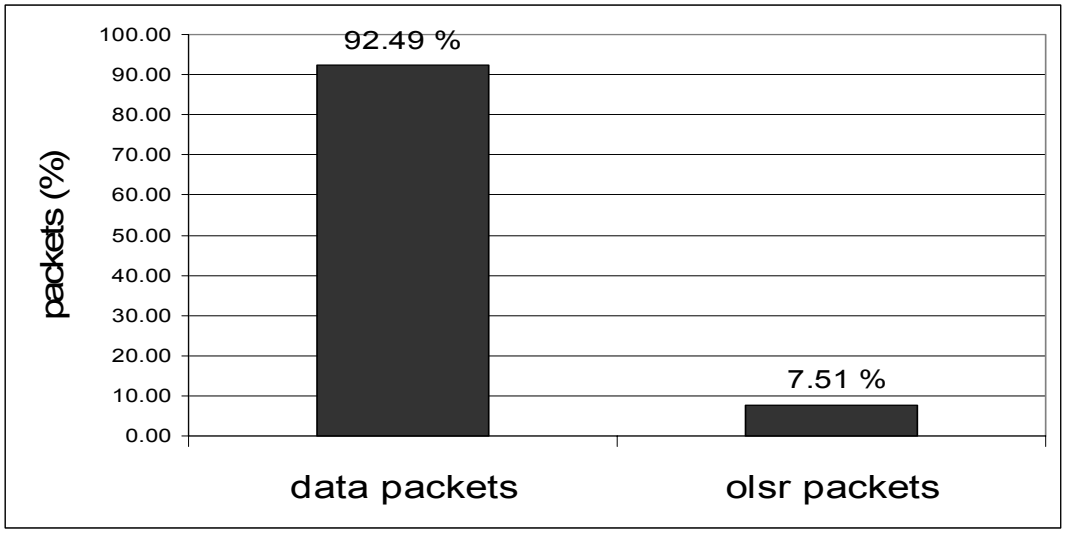

Figure-7: Percentage of UDP traffics from all the traces collected during the whole experimental periods in DUMBONET

We tried to find out the different amount of traffic share in the 79% of UDP packets shown in Figure-6 from all the traces collected. In Figure-7, we showed that, more than 92% packets were created by EasyDC and the rest were OLSR control packets. As OLSR is a pro-active protocol, it creates periodic HELLO and TC messages to determine the network topology and create the routing table. In a stable MANET, OLSR control traffic could be almost constant which depends on the number of node in MANET and the periodicity of each type of packet. On the other hand, all the traffics generated by EasyDC are constant bitrate except the video traffic. As we used periodic broadcast for peer discovery and fixed-bitrate audio codec like GSM, the traffic load in a network (without video traffic) can be completely pre-determined as shown in Table-2.

We see around 19% of ICMP packets as we know EasyDC uses ICMP packet to probe other peer's liveliness. Every peer node sends a register type ICMP packet to all other peers in every 10 *sec*. Even though it feels that sending a packet in every 10 sec periodically does not torture the network that much. But, it also becomes huge control overhead when there are a significant number of nodes are available in the network and every peer tries to send register packet to all other peers in the network. For n number of peers in the network, there will be $n*(n-1)$ register packets in the network in every 10 *sec*. On the other hand, the long duration (10 *sec*) of sending periodic register packets also create cache stall problem. If a peer p_1 sends a register packet to peers p_2 and gets positive reply, p_1 will keep the status of peer p_2 in p_1's cache as alive. Now, if peer p_2 become unavailable just after p_1 updates it's cache, all the packets sent by p_1 to p_2 will be lost in the network. Now increasing the rate of sending register packet will flood the network more quickly creating more congestion in the network, results a scalability problem.

4.2 Burst Traffic Behavior

In case of a video call, a network traffic load is completely dynamic based on the spatial motion presents in the video. The network traffic fluctuation behavior can be seen in a Figure-8 which shows the throughput of different video calls based on time. The trace files collected in headquarter of receiving two video streams of duration 252 seconds from each disaster site at the same time. In Figure-8 at time 55 second, it is seen that the video stream from node 55 occupied more than 200 kbps bandwidth as a result can cause the stream from node 52 to reduce to 0 kbps as they both shared the same satellite link. But on average, the traffic occupancy by a video call is around 80 kbps, hence can support upto of four video calls from different disaster sites.

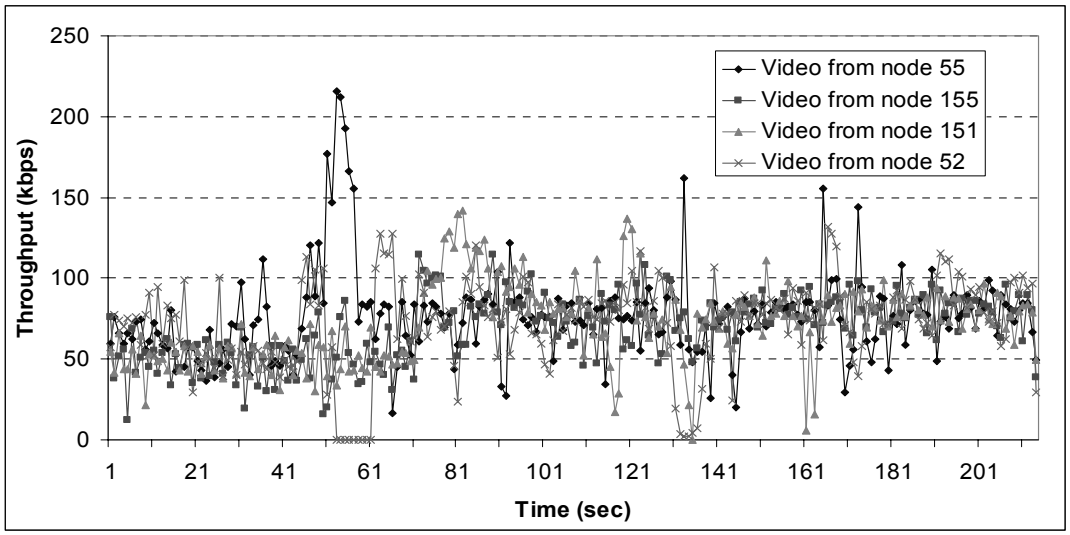

Figure-8: Throughput of video calls from both disaster sites to headquarter; from only one trace collected on 18th November; node 52 and 55 are in site1, and node 151 and 155 are in site2

These kinds of aggressive traffic not only can be dominant to the other video flows, but also can be dominant to other UDP type packets like EasyDC registration broadcast packet, emergency broadcast packet, OpenVPN control traffic or even the OLSR routing control traffic, hence breaking the whole communication system.

Definitely, an improved performance can be achieved with a high bandwidth satellite channel as satellite link is the bottleneck link here. But we can use a First-in-First-Out (FiFo) queue in EasyDC to send bursty traffic like video in a constant bitrate proposed in [11]. This queue would compel the EasyDC to send video traffic in a steadier bitrate hence can prevent being dominant to other traffics. This way, traffics by all video flows or other bursty traffic like chat messages can be shaped to be network friendly. Another way to improve the situation is to allocate separate bandwidth for control traffic and data traffic so that the bursty behavior of data traffic does not affect the control traffics of the network.

4.2 Loss Behavior

Packet loss in a network like DUMBONET could occur in various places like in the MANET, over the satellite and in the end node itself because application layer. The presence of mobile nodes in MANET can cause lots of link failures with other nodes hence fail to transport any upper layer traffic. At the same time, to frequent topology changes creates more routing table changes in the mobile nodes creating failure of packet delivery to the right destination. There are also a possibility of packet loss in satellite network

because of many factors including bad weather, sun interference, channel noise, equipment (like antenna) problems, routing policy etc. As our all the traffic traverse through the same IPSTAR gateway, even though the satellite channel could provides dedicated bandwidth, our traffic can get congested in IPSTAR gateway because of being shared with other traffics.

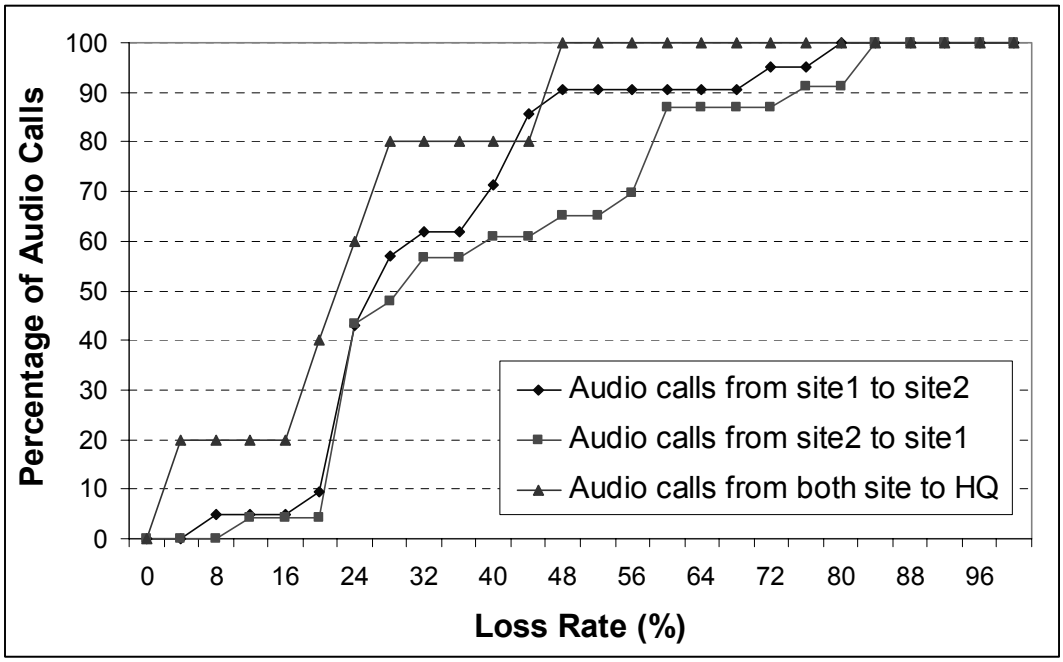

Figure-9: Cumulative distribution of loss rates for audio calls in DUMBONET

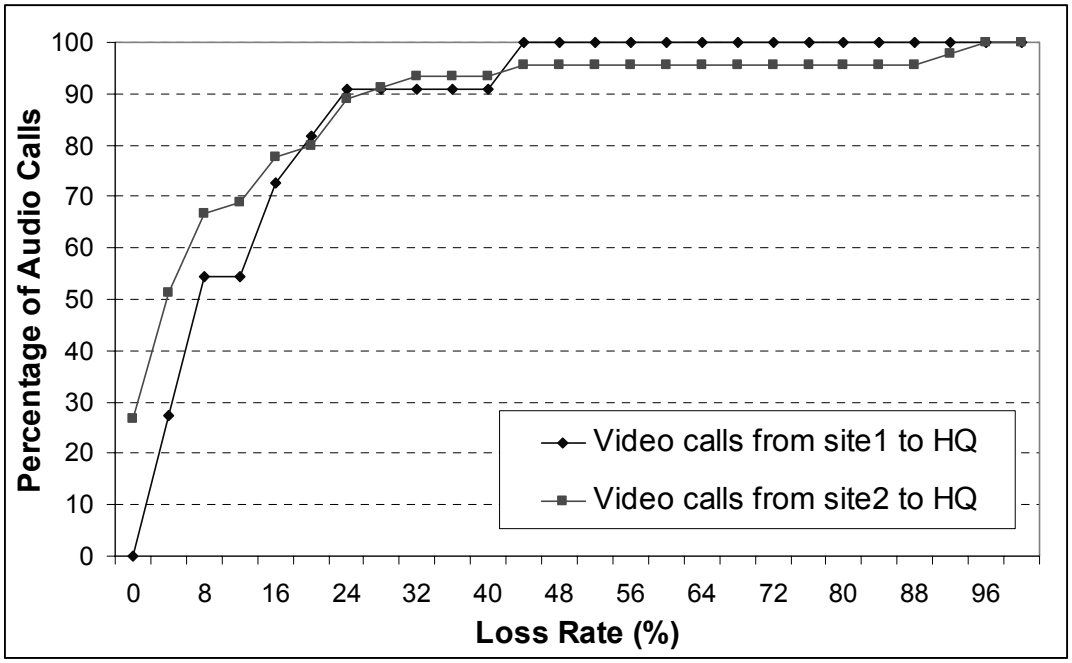

Figure-10: Cumulative distribution of loss rates for video calls in DUMBONET

During our experiments in part I, we focused on the communication possibilities from one site to another site hence sending traffic over 2-hop satellites links. We measured around 100 audio traffic flows during this test period where around 90% calls were from one site to another site. Figure-9 shows the cumulative distribution of loss rates for all audio calls in DUMBONET. Cumulative distribution helps to show the percentage of calls which has a loss rate *x* or less. It needs to mention that, our audio calls are interactive (i.e. bidirectional call). So, if there is an audio communication setup between site1 and site2, the data flow from caller to callee is counted among the flows from site1-to-site2. And, other way traffic means data flow from callee to caller is counted among the flows from site2-to-site1. From the figure, it is clearly seen that communication from site to headquarter (1-hop satellite) has less loss rate than from site-to-site communication (2-hop satellite). As we can see, 42% of site-to-site audio call are having packet loss rate of 24% or less. But, 60% of audio calls can be served with the same packet loss rate for site-headquarter communication. Hence, we can say satellite channels are contributing a huge number of packet loss in audio calls.

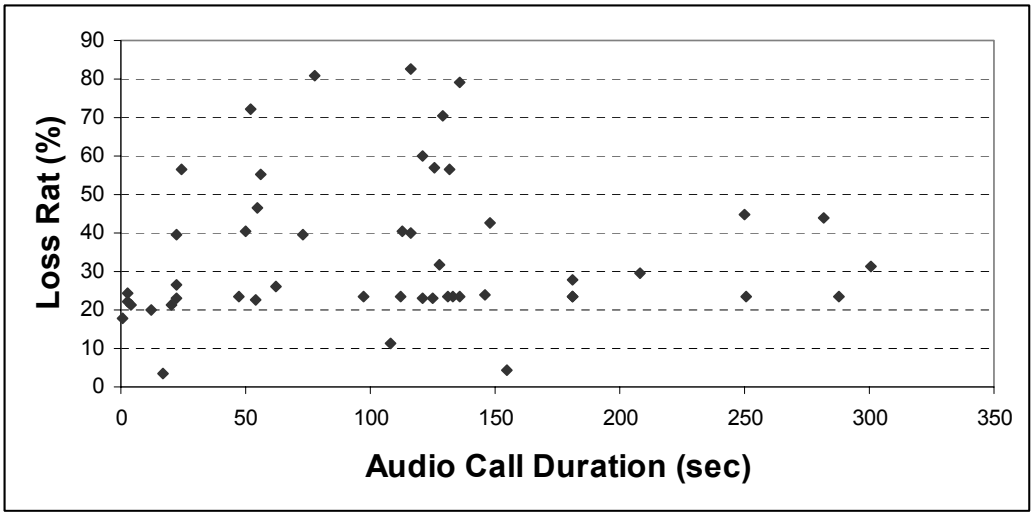

Figure-11: Correlation between packet loss rate and duration for each audio stream

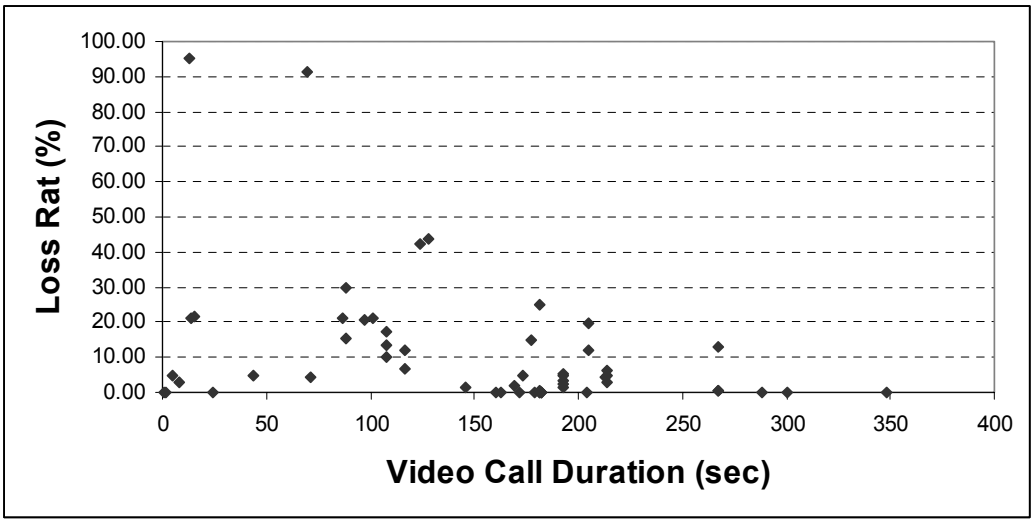

Figure-12: Correlation between packet loss rate and duration for each video stream

Figure-10 shows the cumulative distribution of loss rates for all video calls in DUMBONET. Here unlike the audio calls, our video calls are just one way direction. So, if there has to be any bidirectional video communication, both side (viewer and viewee) has to make call request and has to be accepted by both side. The figure shows that for packet loss rate upto 20% or less, video traffic flows from site2-to-HQ converge earlier than video traffic flows from site1-to-HQ. But the traffic from site1-to-HQ sees a maximum of 50% packet loss where traffic from site2-to-HQ sees upto 90% packet loss. For the video calls from site-to-site, we did able to make some successful communication but we failed to collect enough trace files. So, we did not show them here. We also found that there are a significant amount of packet loss occurs in the MANET site which is explained in the throughput analysis section below.

Another observation tells us that site1-to-site2 communication is better than site2-to-site1. It is because the bandwidth from site2-to-site1 is less than the bandwidth from site1-to-site2 as we mentioned earlier in test-bed topology section. One simple way to improve the lossy behavior by providing more bandwidth in satellite links. But from our observation, we would like to propose a better technique to reduce the lossy behavior or reduce the affect could be caused by lossy behavior.

As we know, headquarter monitors all the disaster sites and manages the overall system by various ways like responding to the emergency broadcast messages or receiving on-demand audio and video calls from each disaster site. At the same time, headquarter can make a call to any peer in any disaster site. Now if a peer p_1 from one $site_1$ need to communicate with a peer p_2 in $site_2$, p_1 just can pass the information to headquarter. And headquarter then gives command or informs to the p_2. By this way, we can achieve several benefits. a) Headquarter will have more information about all peers in all sites hence can have better management system. b) p_1 do not need to make a call to p_2 or vice-versa using a 2-hop satellite channel hence can achieve better audio quality for communication utilizing only 1-hop satellite link. c) If all the on-demand communication routes through headquarter, headquarter can exploit a call-admission like system forwarding the high-priority instructions or information and stalls the less-priority information forwarding.

We also tried to find a relation with traffic loss rate and duration of each call. Figure-11 shows the correlation between packet loss rate of an audio call and its duration. Figure-12 shows the correlation between packet loss rate of a video call and its duration. In both cases, it is seen that average loss rate x for call duration t_1 is higher than the average loss rate y for call duration t_2 where $t_1 < t_2$. We also get another idea that the traffic loss rate do varies over the time. If traffic loss rate would be same for all over the duration, we would see the same loss rate for any duration of flows but which is not the case. The reason for this kind of behavior should be studied further.

4.3 Throughput Analysis

Packet loss in the network can degrade the traffic throughput in a significant level. For each audio and video flow in our network, we categorized them based on different hop counts they have traversed like hop-1 MANET, 2-hop MANET, 3-hop MANET, 4-hop MANET, 5-hop MANET in addition of satellite-hop. Figure-13 shows the average throughput of audio and video calls for each hops counts. As we mentioned, we do not have enough video flow data from site-to-site, here we plotted the throughput of videos measured in site-to-HQ. We can see that the average throughput of a video stream can be as high as around 78 kbps traversing 1-hop MANET and 1-hop satellite link. But it degrades dramatically while it traverses more hops in the MANET and could be as low as upto 15 kbps for 5-hop in MANET and 1-hop satellite link. From our real field work experience also we saw that the quality of video calls were not acceptable at all while the source node more than 3-hop away (and 1-hop satellite) from the destination. As increase of hop-count can degrade the throughput of a video flow, intuitively, it can be said that there are a significant amount of traffics are lost in the MANET site.

The figure also shows the average throughput of audio calls for different hop-counts and 2-hop satellite link. The average throughputs of audio traffics are as high as 12 kbps traversing 1-hop MANET and could be as low as 8 kbps while traversing upto 5-hop MANET. In our real experience also we saw that the quality of audio calls were acceptable upto 4-hops away (and 2-hop satellite) from the destination.

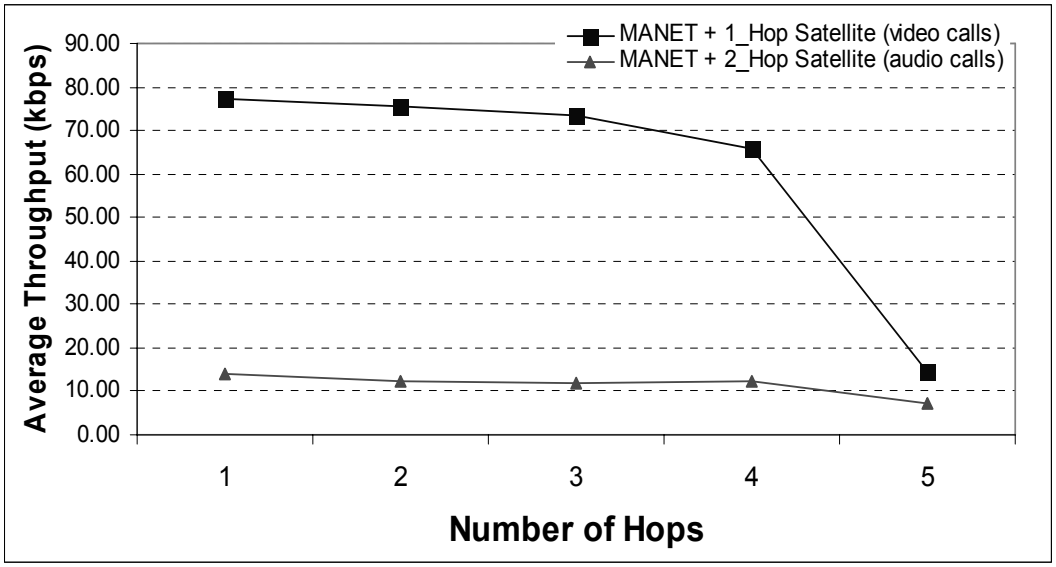

Figure-13: Average throughput of traffics for different number of hops it traverse

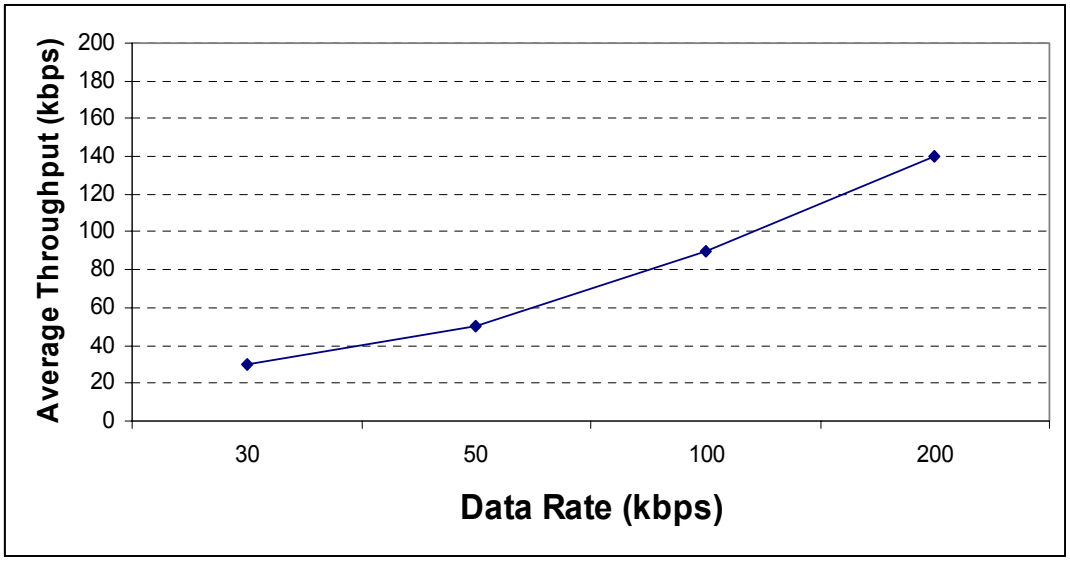

Figure-14: Average throughput of traffics for different number bitrate

But from the throughput analysis for each flow, we may not have idea about the whole network throughput. So, we used iperf to measure the network throughput, specially using the bottleneck link over the satellite. Figure-14 shows the average throughput while UDP traffics were sent in different bitrate and iperf server was 2-hop MANET and 2-hop satellite link away from the iperf client. It shows that the average throughput degrades while the increasing bitrate.

4.4 Delay Behavior

Figure-15 shows the delay behavior of site-to-HQ network collected by using ping tools. A node in Phuket Elephant Camp pings to headquarter in every 5 minutes interval while it was 2-hop MANET and 1-hop satellite distance away. We can see the huge fluctuation of RTT over the satellite which can be more than 4000 milliseconds (ms) sometimes but on average it is around 1184 ms. Figure-16 shows the delay behavior of intra-MANET which shows that the RTT can be near 290 ms sometimes while the average RTT is around 32 ms. We get the idea that the end-to-end (E2E) delay do varies over the time in a MANET or over the satellite. If the E2E delay would be same for all over the experiments, we would see the similar delay behavior in all the traffic flows in our experiment but which is not the case. The reason for this kind of behavior should be studied further.

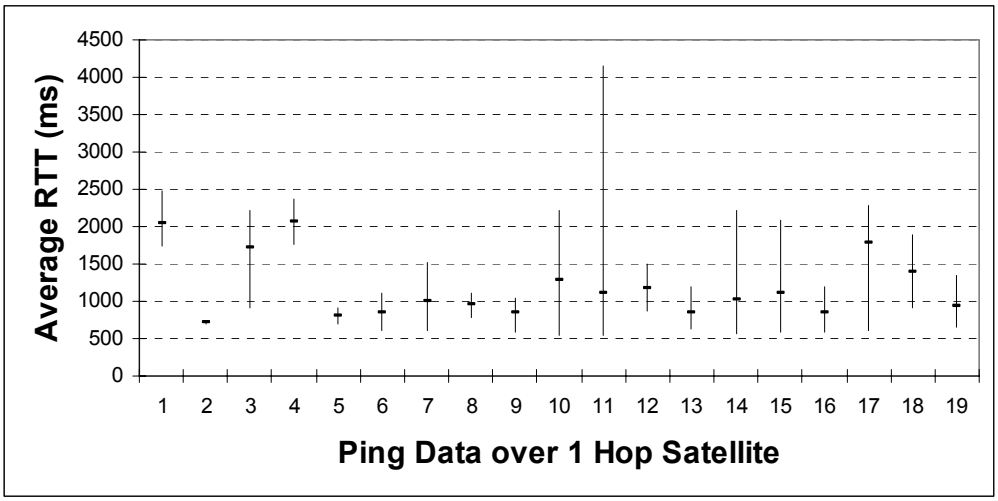

Figure-15: Average, minimum and maximum round-trip-time from MANET to headquarter (1-hop satellite channel), x-axis represents the different instances of delay measurements over different period of time.

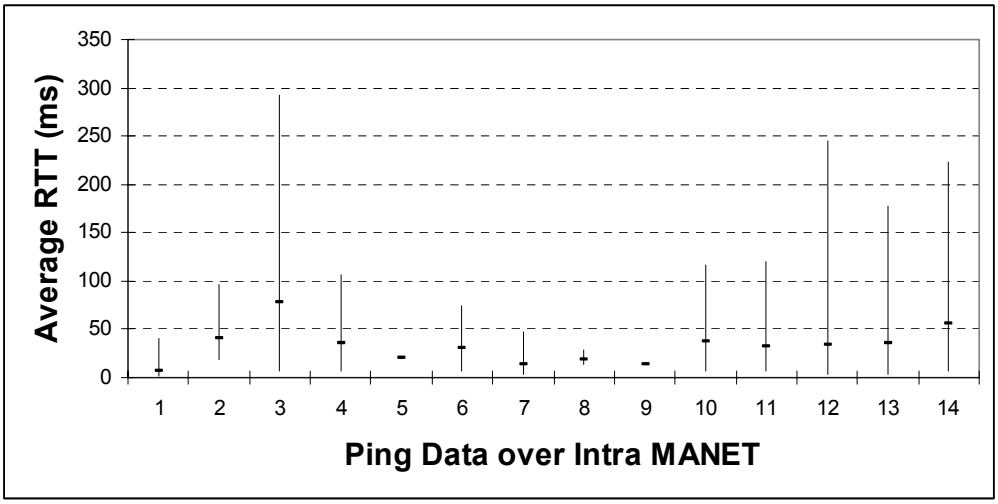

Figure-16: Average, minimum and maximum round-trip-time inside a MANET (without satellite), x-axis represents the different instances of delay measurements over different period of time.

5. RELATED WORKS

There has been several works done on disaster scenarios but very few has real implementations or no data available [12, 13, 14, 15]. Takaaki et al. [12] proposed a data collection and management system for victims on disaster. In our system, the data is collected by an ad-hoc network constructed by handheld and vehicular terminals equipped with wireless interface and GPS receivers. A multiple access control (MAC) protocol has been proposed to allows survivors in disaster areas to establish contact to the base stations (BSs) provided by the rescue team [13] but our DUMBONET can be used on the absence of any BS. This protocol relies on downstream broadcast single-hop wireless transmissions from the BSs to the survivors and upstream multi-hop wireless transmissions. For MAC, the protocol uses a combination of tree splitting and code division multiple access (CDMA). Compared to the single-hop approach for upstream transmissions, it shows that the multi-hop approach can expend less transmission energy, especially when data aggregation is possible at relay points. The real implementation of this protocol is not available. Another proposal on emergency network is a Hybrid Wireless Mesh Network (HWMN) for creating a communication infrastructure where the existing communication infrastructure is damaged or unavailable [14]. They are still in developing process to collect the simulation results in cellular networks investigating different real scenarios that may occur at ground zero. Nelson et al. [15] proposed a bandwidth adaptation algorithm to adjust the allocation of dynamically in a Hybrid MANET-Satellite-Internet Network in response to traffic and link status changes. Implementation issues are discussed with simulation results.

6. CONCLUSION

Designing a robust communications infrastructure for emergency applications is a demanding effort. It should allow for reliable communication among different response organizations over a distributed command and control infrastructure. Additionally, it should facilitate the distribution of warning and alert messages to a large number of users in a heterogeneous environment.

In this system, the control traffic plays the major role to maintain the end-to-end communication even though they are not significant in volume. The various control traffic includes OLSR control packet for multi-hop routing, application control traffic to discover and keep the live state for other peer nodes, and VPN control traffic to allow transparent connectivity among different MANETs.

If there is no load balancing system in the application architecture, the traffic from different node can create huge congestion in the network because of best-effort characteristics of Internet. Some variable bitrate traffic even could be more hostile for the other kinds of traffic hence for the network. It is very important to consider load balancing of different types of traffics or at least prioritize some non-avoidable end-to-end traffic (e.g. control traffic or broadcast messages) as if some message can traverse from disaster site to headquarter and vice-versa. We noticed that we should implement a fair queuing system in the application as if one kind of traffic cannot override the other kinds of traffic.

From our experiments, it found that satellite links are the major source of packet loss. The traffic loss rate is proportional to the number of satellite-hops they traverse. It is recommended not to allow more than one-hop satellite links for any traffic to traverse. Number of hops also plays an important role for multimedia traffic in our system. It is shown that we should not allow more than three hops in any MANET for multimedia traffic traversal.

Extracting real scenario results over different network infrastructures is a valuable analysis tool which can ultimately help improve network survivability in emergency situations. We have presented a partial set of measurements obtained from a recent drill in which we participated on the DUMBO experiment in

AIT and Phuket, Thailand. We should have more fine-tuning of different parameters like delay and loss to develop a better error-prone application for a delay-tolerant network like DUMBONET.

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