Lessons Learned from Real MANET Experiments and Simulation-based Evaluation of UDP and TCP

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Abstract

Although more than a decade of research has been done but pure general-purpose MANET is still not available rather than few prototypes within laboratory due to both technical and socio-economic point of view. Lacking in appropriate guidelines for realistic user traces, mobility models, routing protocols and considering real-life challenges, it is difficult to reproduce any typical scenario in reality apart from simulation. In this paper, difficulties faced to regenerate real-life scenarios have been discussed to clearly identify the gaps in simulation and real-time experiments. Four laptops are used in an open field environment for different scenarios to evaluate a TCP based streaming video application using real OLSR implementation within a IEEE 802.11g wireless network. Corresponding simulations are performed in ns-2 based on the realistic setup parameters achieved from real experiments and finally a comprehensive analysis identifies the generic gaps between these two approaches to evaluate network protocols. Simulation results show better performance than the real-life results due to differ in external influences and protocol implementation although maintaining realistic simulation setups.

Keywords: Real MANET, TCP, OLSR, ns-2

I. INTRODUCTION

Multi-hop wireless ad hoc network is consisted of a number of self-configurable network nodes (e.g. IEEE 802.11-based WLAN, 802.16-based WiMAX, ZigBee, Bluetooth, etc.) to establish an on-demand ad hoc network via multiple hops and paths where no network infrastructures pre-exist. Nowadays, the type of ad hoc networks are usually observed can only support single-hop peer-to-peer networking between several wireless devices. Although multi-hop wireless nodes are used today in different specialised scenarios like in control, logistics and automation, surveillance and security, transportation management, battlefields, environmental monitoring, unexplored and hazardous conditions, home networking, etc. Through the continuous process of standardisations of popular wireless technologies, support from government organisations, intrinsic interest from manufacturers and overall consent from the general end users, multi-hop ad hoc networking is today a reality rather than theoretical research. Although this concept is getting popularity day-by-day but it requires specialised enhancements, integrations and constructions to support multi-hop wireless networking in particular domain. Decades of theoretical research is still not able to provide any specifications and standards for the critical internetworking aspects related to this technology like addressing schemes, topology control, routing mechanisms, cross-layer interactions between different protocols, QoS support, etc. Only few physical (PHY) and medium access control (MAC) standards and drafts are available today either for trial use or prototyping real-life devices. The complete top-down networking architecture is still not well understood and also difficult to find in literature. Most of the theoretical reports and publications have been focused on particular issues rather than concentrate into a complete internetworking model for such paradigm. In this paper, an evaluation of a real MANET experiment has been presented which reveals the gaps with its corresponding simulation results and finally a concise guideline is provided for future elaboration and further research. Following the next section, a brief literature review is provided on the real experimentations conducted at various researches, section III discusses the real-time MANET experimentations along with the comprehensive simulations of the exact scenarios utilising real-time parameters and settings, and finally section IV provides the conclusion and future works.

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II. BACKGROUND AND RELATED WORKS

Theoretical researches mostly overlook the real MANET issues like complex network topology, asymmetric communication links, rapid link quality change, constant reliability of links etc. Most of these influencing factors are difficult to control or even cannot be controlled in real-life experimentations [1]. Node movement, mobility and traffic patterns also play key role in the real MANET experimentations. In [2] and [3] the authors made an extensive review on the difference between theoretical research and reality of this prominent technology. An experimental setup has been made at Carnegie Mellon University, Pittsburgh, Pennsylvania to evaluate the performance of a DSR [4] prototype which consists of five mobile nodes with GPS installed on cars moving in variable speeds [5]. Two stationary mobile IP nodes are also placed 671m apart from the opposite ends of the vehicle travel path and exchange ICMP packets via the five multi-hop mobile nodes. Another MANET real-time experiment has been conducted at Sydney Networks and Communication Lab with four fixed and one mobile node with IEEE 802.11b network adapters, fixed 1Mbps data rate and 5m transmission range [6]. The experiment suggested that choosing unreliable direct links rather than multi-hop reliable links are resulting poor performance in MANET routing protocols. In the University of Washington and Stanford University, 100 autonomous mobile robots are used to create a test-bed consisted of a maximum five hops MANET with 1 Mbps throughput [7]. The network broke down when all the nodes wanted to join at the same time which happened because of unreliable routing protocol implementation. Three static nodes with onboard GPS and IEEE 802.11b network interface are used to evaluate the performance of GPSR [8] protocol at the University of Mannheim which discovers 400 Kbps throughput while very low performance in mobile scenario where routing broadcast packets were often lost. A comparison of four MANET routing protocols has been performed at the University of Illinois at Urbana-Champaign with 33 mobile nodes which finds high overhead of control packets for reactive protocols than the proactive ones [9]. The original DSR protocol implementation from the popular network simulator ns-2 [10] is used in real-life MANET with four static and two mobile nodes at Rice University, Houston [11]. The average packet delivery ratio was 95% with overall latency of 30ms which justified the ns-2 implementation. A DSR implementation was tested at the University of Colorado with 10 nodes where some nodes are remote-control mini planes [12]. The experiment achieved 250 Kbps throughput with 30ms latency over a maximum three hop MANET. Twenty cars equipped with four directional antennas and IEEE 802.11b network interface each were used in an evaluation of a link state routing protocol Hazy-Sighted Link State (HSLS) [13] at BBN Technologies, Cambridge [14]. The experiment outperformed similar type of experimentation using OLSR [15] protocol. In another experiment at the Institute for Informatics and Telematics, Pisa, eight nodes are used to examine AODV [16] and OLSR routing protocols with a peer-to-peer (P2P) networking system, CrossRAOD [17]. In experiments it is found that the CrossRoad over OLSR outperforms traditional P2P systems over AODV. Some 9 to 37 nodes are used within four mobility groups in indoor at APE test-bed, Uppsala University on AODV and OLSR protocols and it is found that the approach of choreographing node movement is suitable for real-life MANET testing [18]. Although years of experimentations are carried out, well-justified methodology, network architecture and benchmarks are yet to define. Therefore, it is still difficult to reproduce the experimental results and implement any original research ideas.

III. MANET PERFORMANCE EVALUATION

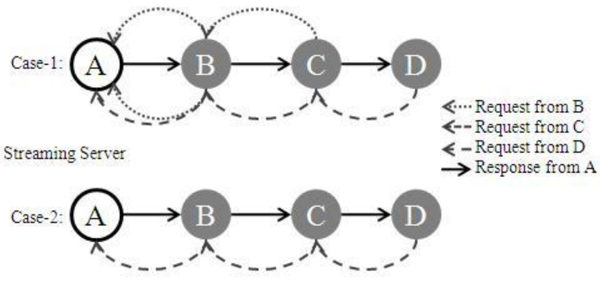


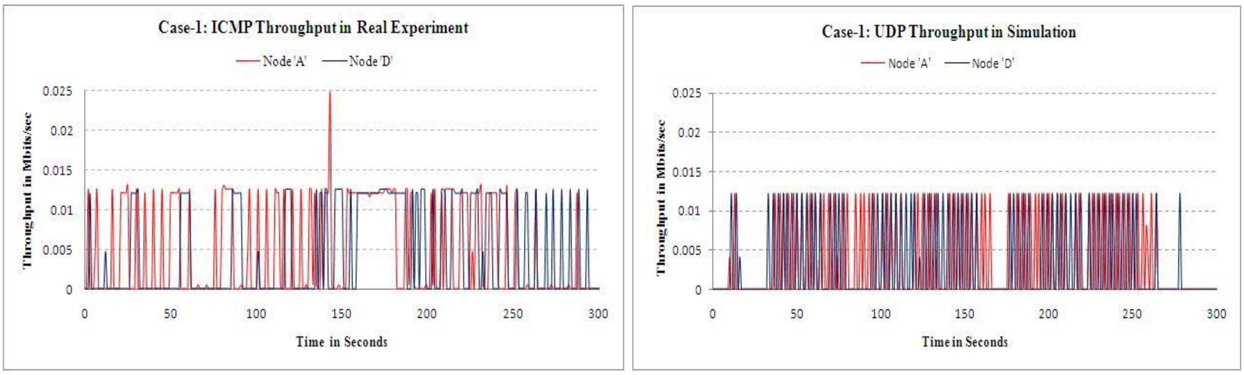
Figure 1. Experimental node topology and request/response flows

A. Real-life MANET Experimentations

In this real-life MANET experimentation, a string node topology with four static nodes is considered as shown in Figure 1. To evaluate ICMP and UDP performance only case-1 is considered for both experiment and simulation. Frequent fluctuations are observed in both experiment and simulation of case 1 as shown in Figure 2. (a) and (b) due to unstable wireless links between the end nodes (i.e. node 'A' and 'D'). Experimental results show low frequency of fluctuations as ICMP requests are sent and the nodes wait for a time-out period to receive the replies.

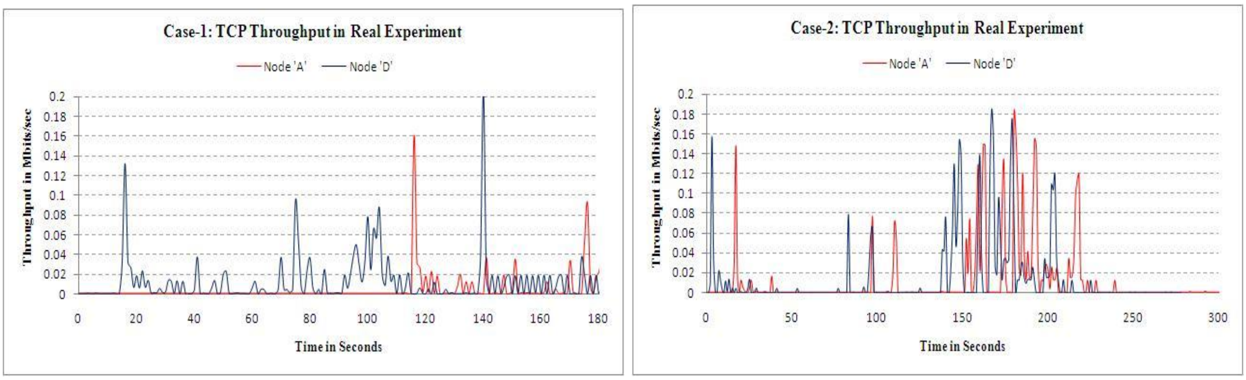
To evaluate TCP performance a streaming video application from node A to node D for two different cases is considered. In first case (180 sec), node A is streaming video and all the other three nodes are watching this video in real-time while in the second case (300 sec), the two relay nodes i.e. node B and C are restricted to request and retrieve the real-time video. In both the cases, TCP performances are evaluated considering data packet capturing only on node A and D using Wireshark protocol analyser and capturing tool. A real-world implementation of OLSR protocol (i.e. Olsrd version 0.6.0 [19]) has been used on the four wireless nodes in an open field environment separating each node by approximately 40m of distance. Node 'A' acts as the streaming video server using Broadcam, a freely available streaming tool. Other nodes i.e. node B, C and D can able to send HTTP request via web browser to the streaming server for live video that is being captured by node A.

From Figure 3. (a) it is seen that node D (n3) is continuously requesting for streaming media but as the other two relay nodes are interrupting video transmission therefore responses from node A could not able to reach to it until at time nearly 120th second. Therefore, it is clearly seen although the maximum throughput burst is higher than the UDP transmission as shown before but the average throughput still under the acceptable level to transmit real-time video over multi-hop ad hoc network with two relay nodes also are receiving data at the same time.



(a) (b)

Figure 2. ICMP and UDP throughput performance for node A(n0) and D(n3) in (a) real MANET experiment and (b) simulation of case-1



(a) (b)

Figure 3. TCP throughput performance for node A(n0) and D(n3) in real MANET experiment of (a) case-1 and (b) case-2

In Figure 3. (b) (case-2), the two receiving relay nodes are restricted to watch streaming video while they are only forwarding data packets towards the end node D. Therefore, from the very beginning of the experimentation a sequence of request and response can be seen. Although there is frequent fluctuations throughout the total period of experimentation but the response time for live streaming video from the server node i.e., node A is quite less than case-1. From here it can be clearly seen that, interruptions from relaying nodes within a multi-hop ad hoc network can easily degrade the overall application performance as well as make wastage of previous bandwidth for end-to-end data transmission.

Statistical analysis also indicates the number of TCP packets received by node D has been increased from case-1 to case-2. Again the average packet size and average bytes/second have been also increased while average packets/sec has been slightly decreased in the later experiment. Again, it can be noticed that, the overall experimentation time has been increased from 180 to 300 seconds due to the fact that TCP requires three-way handshaking to maintain an end-to-end connection therefore requires a minimum time to response the ACK back from node D to node A. Therefore, the total time has been increased to understand this effect more clearly and allow node A to receive corresponding ACK packets from node D. The aggregated network throughput of case-2 is 0.000855595 Mbps which is slightly better than case-1 which is 0.000382492 Mbps. It also shows the increased number of transmitted and received packets from case-1 to 2.

B. Realistic MANET Simulations in ns-2

To compare the real MANET experimentation results and identify the gaps between real-life challenges and simulation setup, six corresponding simulation scenarios have been arranged. Popular network simulator ns-2 is used to demonstrate the multi-hop wireless ad hoc networking capability with 80211Ext extension developed by Mercedes-Benz/Karlsruhe team [20]. All the latest bug fixes have been applied to get optimum output. UM-OLSR [21], a popular version of OLSR protocol (which is developed in University of Murcia, Spain) for ns-2 has been used in the simulation. Four similar type of network node with similar node configuration have been used to simplify the overall simulation process along with all default IEEE 802.11g parameters. To match with configuration of Olsrd tool that has been used for the real-world experiment, several parameters have been adjusted into UM-OLSR like Willingness=3, HELLO_INTERVAL=5sec and TC_INTERVAL=3sec. A generic Cisco Aironet 802.11a/b/g Wireless PCI adapter has been chosen with a receiver sensitivity of -71dBm and transmit power of 15dBm for 54Mpbs data rate over IEEE 802.11g [22]. Shadowing propagation model with path loss exponent (β) of 2.3 and shadowing deviation (σ_{dB}) of 6.0 has been used to closely model the simulation environment as realistic as possible. Distance between each node has been chosen 40m with a correct packet reception rate of 60% on average to generate the receive threshold value

TABLE I. PHY AND MAC LAYER SIMULATION PARAMETERS

Parameters	Values
ns-2 Version	2.34
PHY and MAC	IEEE 802.11g with 80211 PHYEXT
Frequency	2.4GHz
Propagation Model	Shadowing, with path loss β=2.3, σdB=6.0 for 40m distance and 60% correct packet reception rate
PHY Layer Parameters	
Rx Sensitivity	-71dBm @ 54Mbps for IEEE 802.11g
Transmit Power	15dBm @ 54 Mbps for IEEE 802.11g
Receiver Thresh.	-63dBm, calculated based on the propagation model
Modulation	QAM64
Header Duration	20µs
Preamble Capt.	True
MAC Layer Parameters	
Data Rate	54Mbps with basic data rate 6Mbps
CWMin	15
CWMax	1023
Slot Time	9µs
SIFS	10µs
Other Parameters	
Antenna Type	Omni-directional with antenna height 1.5m
UDP Packet Size	1500 bytes, CBR over UDP
TCP Packet Size	1460 bytes with window size 8192, FTP over TCP
Routing	UM-OLSR
Simulation Time	For UDP 300 and 120sec, for TCP 180 and 300sec

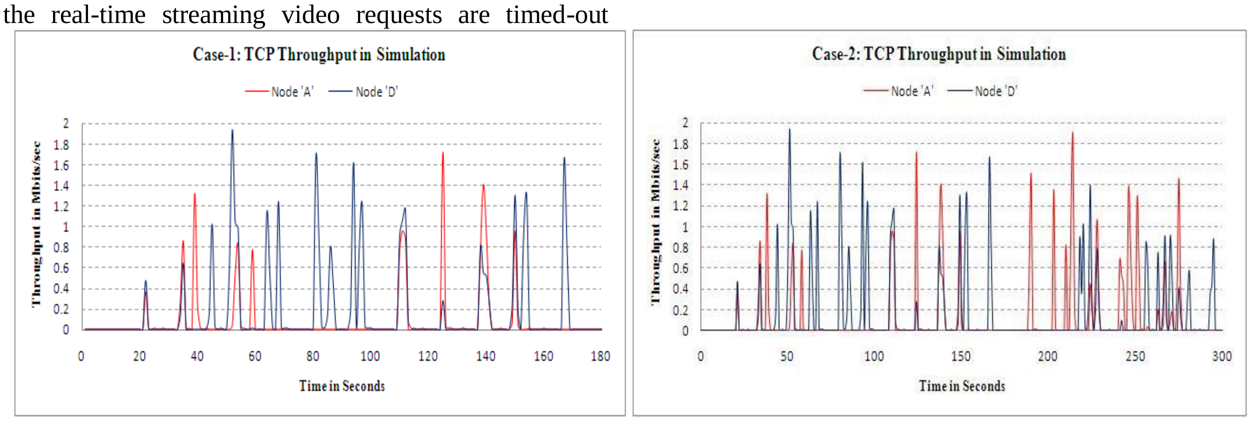
with the corresponding propagation model based on the experimental results. For the transport layer protocols based on the analysis from the Wireshark trace files generated in the real-world experiments, UDP packets sending interval has been chosen to 0.005sec for each 1500bytes and TCP window and packet size are chosen to 8192 and 1460bytes. Detail parameter settings for the overall simulation process can be seen from TABLE I.

From the UDP simulation results in Figure 2. (b), it is seen that average throughput performances are similar in both experiment and simulation. Comparing with the experimental results, CBR packets are constantly sent based on the interval periods given in **Error! Reference source not found.**; hence show higher frequency of fluctuations in data throughput.

Similarly to evaluate TCP performance over MANET in real-life experimentations, simulation results shown in Figure 4. indicates similar characteristics with Figure 3. . Comparing the results, node D also cannot able to get timely replies from the server node A, therefore most of the real-time streaming video requests are timed-out although before 100th second and very few replies are reached to node D. Again for case-2 results shown in Figure 4. , without the interruptions from the relay node B and C, node D periodically gets the response from the streaming server. Recall from case-2 in Figure 3. which also shows similar characteristics without the relay nodes receiving streaming video data from the server node A. In both the cases, throughput analysis show common characteristics apart from the TCP implementation in real world NIC on mobile nodes and the simulator implementation, therefore, several dissimilarities can be found while in case of TCP retransmission, TCP ACK and TCP SYNC messages. Therefore, in most of the cases, it is very difficult to regenerate real-world scenarios in simulation and real environment can easily be affected by any external influences and interaction in term of packet data communication. The average network throughput is 0.122376 Mbps and 0.115220 Mbps for simulation case-1 and 2 respectively which are quite higher than the real-life experimental results. End-to-end delay is higher in case-2 than case-1 which closely similar to the real experimental results. The overall TCP performance behaviour and trends of simulations are closely matched with the real experimentation case-1 and 2.

IV. CONCLUSION AND FUTURE WORK

A comprehensive study and analysis have been done in this paper with ICMP/UDP and TCP over MANET in both real world environments and simulation-based studies. The simulation scenarios and parameters are adjusted following the findings of real experiments and therefore in the analysis phase close similarity in both UDP and TCP characteristics have been identified clearly. Regenerating real-life scenarios are very hard to achieve therefore many inherent properties of underlying protocols cannot be identified in the simulation phase. Simulation results show better performance comparing to the real experimental results for UDP and in both the cases for TCP. Real-life OLSR protocol implementation has been used in Windows based machine with different types of NIC to reflect appropriate and realistic MANET environments. To match with real world experiments OLSR implementation for ns-2 simulator has been used along with IEEE 802.11g PHY and MAC layer parameter settings with real world NIC parameter values and realistic propagation model calibration. The overall



(a) (b)

Figure 4. TCP throughput performance for node A(n0) and D(n3) in MANET simulation (a) case-1 and (b) case-2

experiments regarding the evaluation process motivates to the deep understanding of realism between reality and theoretical research which is necessary to turn theory into reality. Further case studies along with low level performance metric analysis and different topological models and mobility patterns will be considered into future work.

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