Evaluation of FTP Throughput in Mobile Ad-hoc Networks Running AODV-UU Routing Protocol

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Abstract: **Nodes in Mobile Ad-hoc Networks (MANET) act not only as source or destination but also as intermediate nodes (routers). This makes multi-hop wireless communication possible. In this paper we evaluate FTP throughput in MANET testbed running AODV routing protocol implementation from Uppsala University (AODV-UU). Visualization and configuration of testing environments were done by VACUum, a software with graphical interface developed by Ericsson Nikola Tesla Research department solely for these purposes. As expected, in single-hop there were no difference between achieved FTP throughput in AODV and pure ad-hoc mode. In multi-hop environment with collocated nodes, the FTP throughput will scale inversely proportional with hop number.**

Keywords: **ad-hoc networks, AODV-UU routing protocol, MANET, WLAN, multi-hop, FTP, Throughput**

I. INTRODUCTION

In Mobile Ad hoc Network (MANET) each wireless mobile node acts not only as source or destination of the data but also as router, routing the packets for other hosts. Typically for ad-hoc networks, MANET networks characterize absence of any centralized control or fixed network infrastructure. Such a network may operate in standalone fashion, or may be connected to some fixed network through gateway. MANET networks are quick and easy to deploy so applications may include cases where other wireless networks are not feasible, economical or practical. Examples are emergency disaster relief, battlefield command and control, mine site operations, sensor networks and wireless classrooms or meeting rooms in which participants wish to share information or to acquire data.

Since MANET networks are generally multi-hop, some kind of routing in wireless domain cannot be avoided. Protocols used in wired networks are not appropriate for ad hoc mobile networks because of the temporary nature of the network links and additional constraints on mobile nodes i.e. limited bandwidth and power [6]. MANET routing protocols must have high level of adaptability in order to keep up with network topology changes.

Wireless links have significantly lower capacity than their hardwired counterparts. In addition, the realized throughput of wireless communication is often much less than a radio's maximum transmission rate, due to fading, noise, interference conditions, etc [7]. Also, routing information's overhead, processing power of each mobile node and overall number of mobile nodes influence on available throughput, which is the reason why throughput consumption and scalability issues of MANET networks must be investigated. The investigated scenario involves the evaluation of FTP throughput performance between AODV nodes in a static ad hoc environment. This scenario resembles the conditions encountered in conference rooms, class rooms, hotel rooms or home networks.

The rest of this paper is organized as follows: First, AODV routing protocol is briefly discussed. Next section details experimental set up of the test-bed. The fourth section shows the obtained results, together with the analysis. The final section is a concluding summary.

II. AODV ROUTING PROTOCOL

Ad hoc network routing protocol algorithms includes processes such as discovering, establishing, recovering and maintaining routing paths. AODV is the one of the leading routing protocols adopted by IETF for MANET. It is on-demand algorithm that builds routes between nodes, but only as desired by source nodes, and maintains these routes as long as they are needed. This protocol offers a quick adaptation to dynamic link conditions, low processing and memory overhead, and low network utilization. It is also loop-free, self-starting algorithm, and scales well to larger numbers of mobile nodes. Adaptive routing decisions in AODV are made hop by hop, where AODV nodes record the information of only a single route to the destination in the routing table using hope count as the only metrics [6].

AODV uses 4 types of control messages. They are *the Route Request (RREQ), Route Reply (RREP), Route Acknowledgment (RREP-ACK) and Route Error (RERR) messages* (Figure 2.). Sequence numbers in AODV play a key role in ensuring loop freedom. Every node maintains a monotonically increasing sequence number for itself. It also maintains the highest known sequence number for each destination in the routing table, called destination sequence number which is included with RREQ, RREP and RERR messages [8].

In our test-bed network we used AODV-UU implementation [2] of the AODV protocol. There are several AODV implementations available on Internet but AODV-UU seems to be the most complete, stable and updated one.

III. MEASUREMENTS ENVIRONMENT AND METHODOLOGY

Our experimental measurements were done on S-Net laboratory network. S-Net Mobile Ad-hoc laboratory network is a testbed built up within S-Net Research project at Ericsson Nikola Tesla d.d., Research and Development Center in order to evaluate usage of mobile ad-hoc networks.

Different factors such as radio frequency interference signal strength, node mobility, hop number and data traffic pattern may affect performance in multi-hop MANET network. We will be focused on throughput – hop-number

dependencies in order to define number of hops that data can traverse and still provide acceptable throughput to potential user. Under acceptable we imply at least dial-up speeds (~ 56kbps). In this way we also discuss coverage area issues of the MANET networks. Different effects on throughput such as node mobility and frequency interference are ignored in these measurements.

TABLE 1
HARDWARE CONFIGURATIONS USED IN MEASUREMENTS

	RAM [MB]	CPU	Frequency
PC1	768	Intel® Pentium® 4	2,00 GHz
PC2	512	Intel® Pentium® M	1,73 GHz
PC3	512	Intel® Pentium® M	1,60 GHz
PC4	256	Intel® Pentium® 4	1,60 GHz
PC5	768	Intel® Pentium® 4	2,00 GHz
PC6	512	Intel® Pentium® 4	2,00 GHz

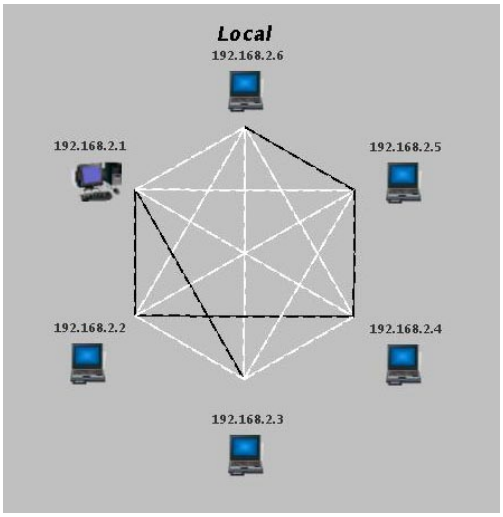

Fig. 1 "Forced multi-hop" example. All nodes are inside the same room (screenshot taken from VACUum software)

A. Hardware

MANET networks in real life are or can be very heterogeneous in sense of hardware capabilities. Having this in mind, requirement for all nodes to have same hardware capabilities is not critical. Hardware capabilities of hosts used in our laboratory measurements are listed in Table 1. Wireless LAN cards used in our network are Zydas zd1211 chipset based 802.11g Wireless USB 2.0 Adapters.

B. Software

Testbed network consists of 6 machines (nodes) that run Fedora Core 4 with 2.6.11-1.1369_FC4 kernel [1]. Routing protocol implementation that was used is Uppsala University AODV implementation (AODV-UU)[2]. Version that was used is AODV-0.8.1. Although version 0.9.x introduced some fundamental changes (e.g. kernel based instead user-space forwarding) version 0.8.1 is recommended for stability and gateway functionality.

Besides AODV-UU routing protocol implementation, the laboratory network comprises visualization and configuration utilities (VACUum), software developed within S-Net project at Ericsson Nikola Tesla d.d., R&D Center on FESB. VACUum is java-based software with graphic user interface (GUI) that allows users to:

- Scan the wireless network (scan results comprise number of nodes, node's IP address, type, and links between nodes)
- Run AODV-UU routing protocol implementation on both, local and remote computers
- Disable (or enable) some direct wireless connections by discarding frames at MAC layer according to their hardware address and in that way force multi-hop connections
- Redraw (rescan) network topology to check if it is up-to-date

C. Environment

Since *MANET* networks (running some of the special routing protocol, such as AODV in our case) are special case of ad-hoc networks, there are some requirements in wireless card configuration that should be met in both cases. All nodes should share same IP sub-network address space, same ESSID (network identifier), channel (frequency) and rate.

Although all used wireless LAN cards support IEEE 802.11g standard (speeds up to 54 Mbit/sec) all our measurements where done at 11 Mbit/sec, which is maximum throughput defined by IEEE 802.11b standard. We used recommended class C private IP address range (192.168.2.x addresses) and default network mask for class C (255.255.255.0).

```
#iptables –A INPUT –m mac --mac-source \
<MAC_ADDR> –j DROP
```

All machines were located inside one laboratory room so visibility constraints necessary for multi-hop data transfer are artificially accomplished (this is sometimes called "*forced multi-hop*"). Data frames are filtered according to their MAC addresses. Therefore, MAC address filtering is done via *iptables* Linux command tool [3]. Since routing protocol implementation resides at higher level of OSI model (than MAC layer), AODV-UU functions as it would function in real multi-hop environment.

Radio frequency interference and node mobility effects are considered to be minimal and are ignored. To avoid unidirectional links, *iptables* command tool with corresponding MAC addresses should be entered on both participating machines (on a single link). Number of links in the network with n wireless nodes (without any visibility constraints, "full mesh" topology) is:

$$\frac{n*(n-1)}{2} \qquad (1)$$

Our laboratory network with 6 nodes shown on Figure 5. has totally 15 wireless links. VACUum software is used to set MAC address filters from graphic user interface rather than from console (Fig. 1.).

In the VACUum 1.0 software, *nmap* ("Network Mapper") [4] command tool is used, which is a free open source utility for network exploration or security auditing. The example of command used for mobile ad-hoc network scanning in our measurement is:

```
# nmap -sP -ttl 1 -n 192.168.2.1-6
```

In the above command, *Ttl* (time-to-live) switch is set to 1 (hop), because we are interested only in direct (single-hop) connections. Switch *sP* select ping scan (only determine if host is online, no port scanning). Switch *n* disables DNS resolution for faster output. If the command *nmap* is run as root user, (in our case) output additionally contains MAC address of WLAN interface for all discovered non-local hosts. The discovery cycle initiated from local node include remote execution of the *nmap* command on any discovered live node in the designated range of IP address regardless is it seen from starting or any other node in discovery chain. On that way we build up the topology matrix comprising IP addresses of live nodes in matrix diagonal and ones at intersections of direct (single-hop) connected nodes at other positions of matrix (Fig. 3).

192.168.2.1	1	1	1	1	1 *MAC1*
1	192.168.2.2	1	1	1	1 *MAC2*
1	1	192.168.2.3	1	1	1 *MAC3*
1	1	1	192.168.2.4	1	1 *MAC4*
1	1	1	1	192.168.2.5	1 *MAC5*
1	1	1	1	1	192.168.2.6 *MAC6*

Fig. 2. Topology matrix for full mesh topology

192.168.2.1	1	0	0	0	0 *MAC1*
1	192.168.2.2	1	0	0	0 *MAC2*
0	1	192.168.2.3	1	0	0 *MAC3*
0	0	1	192.168.2.4	1	0 *MAC4*
0	1	0	1	192.168.2.5	1 *MAC5*
0	0	0	0	1	192.168.2.6 *MAC6*

Fig. 3. Topology matrix for "chain" topology

A row in matrix represents a node. Besides topology matrix that defines connectivity within the network, last column of the matrix contains MAC addresses of the hosts (Fig. 2. and Fig. 3.). The topology matrix is base for visualization. Without any knowledge of their relative positions VACUum v1.x software places all nodes in to angles of a regular polygon as shown on Fig. 1. Nodes are represented with small picture and IP address. Links between nodes are represented with lines, where white links are disabled, and black links are enabled by VACUum software.

Topology of interest in our measurements is so called "chain topology". This means that all nodes will be able to communicate only with two (pre-selected) neighboring nodes (data from other nodes is discarded at MAC layer), so we will have only one route from each source to each destination. This is the reason why in topology matrix for "chain" topology we have placed ones above and below IP addresses settled in diagonal of topology matrix (Fig. 3). Of course, end nodes will have only one neighbor, and accordingly to them ones will be placed. In other case we would have "circle topology" and two routes to all destinations. In this way we "force" pre-selected routes by disabling all others.

Last octets of the IP address of all nodes in the chain are used to name different chains. For example, chain "234" consists of hosts with 192.168.2.**2**, 192.168.2.**3**, 192.168.2.**4** IP addresses (all hosts are in 192.168.2.x network).

IV. RESULTS

A. *Single-hop transfer*

First we will compare throughput measurements of single-hop FTP transfer in pure ad-hoc mode (without AODV routing protocol, only single-hop transfer is possible) and single-hop FTP transfer using AODV-UU routing protocol implementation. File used in transfers was approximately 16 MB of size. There were totally 70 related measurements. We used 5 different "chains" (single-hop direct connections) and for each chain in each mode (for simplicity we can call them *Ad-hoc* and *AODV* modes) we made 7 measurements. Fig. 4 shows that in single-hop it is irrelevant which mode is used for transfer because average values (734 Kbytes/sec for Ad-hoc and 736 Kbytes/sec for AODV) and standard deviation (4,64% for Ad-hoc and 5,97% for AODV) are almost the same. These are expected results because once AODV has route to destination and it is relatively often used (during FTP transfer route is used continuously) there is no additional delay caused by AODV protocol. Eventually, some delay could be introduced if route is not used often because AODV starts route discovery process automatically after expiration of route caching timeout.

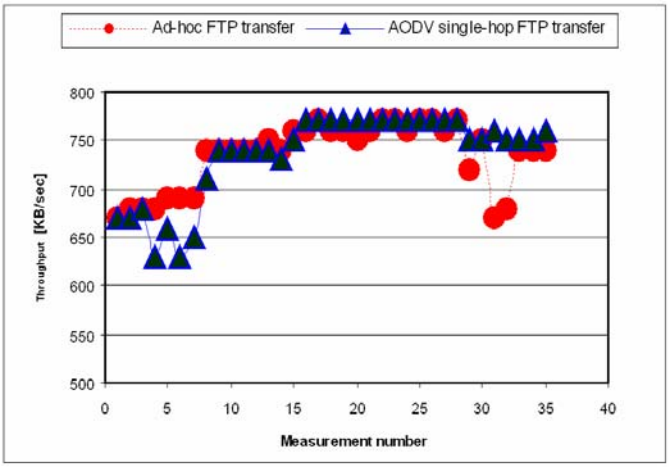

Fig. 4. Ad-hoc and AODV single-hop FTP transfer comparison

B. *Forced multi-hop transfer*

1) *Idealized throughput – hop number dependency*

Although measured throughput results might seem very logical and simple, theory behind it, is not trivial. This is due to a number of variables that are affecting throughput in mobile ad-hoc networks:

- Hop number
- Frequency interference
- Signal strength
- Distance between nodes
- Processing and buffering capabilities of each node involved
- Node mobility
- Data traffic pattern

Forced multi-hop environment that we use is far from real-life scenarios but still it gives many insight of throughput scaling in mobile ad-hoc networks.

Since all hosts in the network are operating at the same channel (frequency) in multi-hop transfer only time division multiplexing is possible (Fig. 5). Ideally, we have static (non-moving) hosts that are in vicinity to each other. There is no frequency interference and no obstacles between hosts. Processing and buffering times in intermediate nodes are considered to be zero. In this case throughput will be inversely proportional to hop number (*N*) (equation 2).

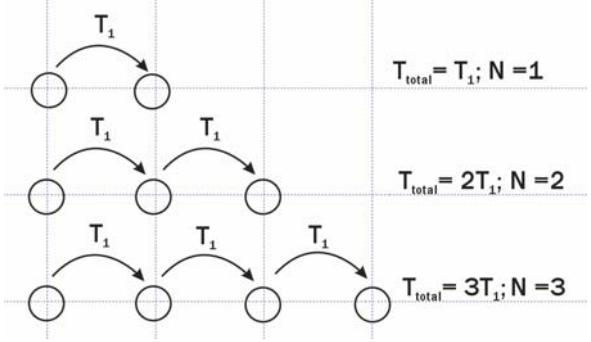

Fig. 5. Time domain multiplexing in multi-hop transfers

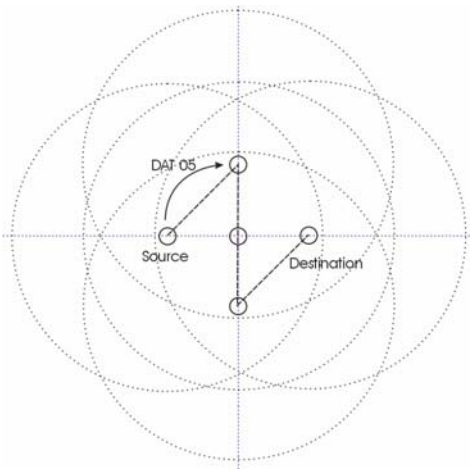

Fig. 6. Artificial chain topology. Only one transfer at the time is possible because at physical layer all hosts "see" all others.

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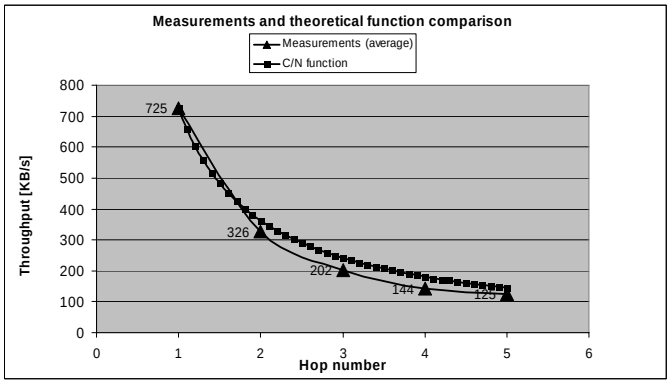

Fig. 7. Throughput – hop number dependency graph

Since all host are located within the same room (all hosts "see" all other hosts on physical layer; visibility constraints are achieved artificially at MAC layer, Fig. 6) only one transfer in the whole chain is possible at the time. Thus, if we ignore processing and buffering times, total transfer time (T_{total}) is equal to a product of a single-hop transfer time (T_1) and number of hops (*N*) [5]. Constant C_1 is equal to throughput of single-hop transfer.

$$Throughput_{colocated} = \frac{Size}{T_{total}} = \frac{Size}{N * T_1} = \frac{C_1}{N}\left[\frac{Kbytes}{Sec}\right] \quad (2)$$

$$C_1 = \frac{Size}{T_1}\left[\frac{KBytes}{Sec}\right] \quad (2a)$$

Coverage areas of the nodes in artificial chain topology (collocated nodes) are almost concentric (nodes are relatively very close to each other). Total coverage area is almost the same as a single node's one (Fig. 6).

Furthermore, if "chain" topology is not artificially achieved, which means that nodes form chain topology although they are not all situated in the same coverage area, they form real chain topology, implying that, within the chain, multiple transfers would be possible at the same time. Nevertheless, real chain topologies (possible due to a special MANET routing protocol such as AODV) are very useful because they extend coverage area of the classical wireless networks. This is one of the greatest benefits of the MANET networks.

2) *Measurements*

Our environment is very similar to the idealized environment where hosts are simply collocated within the same room and visibility constraints are artificially accomplished. There were totally 126 related measurements. Fig. 7 shows two different curves: measurements curve and theoretical optimum curve for collocated nodes (C/N function). We can see that measured values are fairly close to the theoretical optimum but they never exceed it. This confirms initial assumption that our environment is very similar to ideal collocated environment. Differences are introduced with imperfections of our laboratory model and assumptions made when calculating formula defined in relation (2).

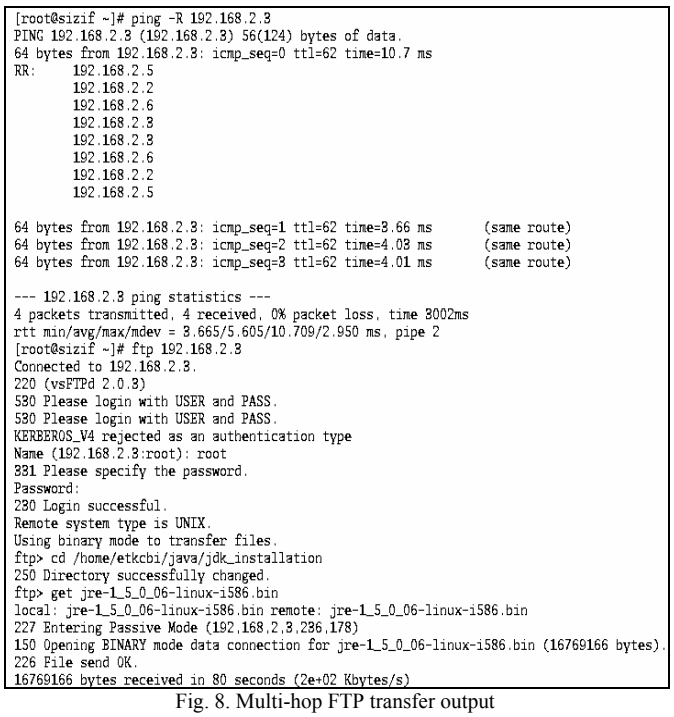

Fig. 8. Multi-hop FTP transfer output

Output of the `ping –R 192.168.2.3` command (Fig. 8) shows all (wireless) interfaces that ICMP packet (request and reply) traverses. This evidences that FTP transfer really use multi-hop route (on the figure "chain" 5263 is used). After successful authentication to the remote host, FTP transfer took place. Finally, time and average speed of the transfer were reported. The procedure was similar for all other measurements.

V. SUMMARY AND CONCLUSION

This paper deals with evaluation of FTP throughput in Mobile Ad hoc Networks (MANet). The testbed network run AODV-UU implementation of the routing protocol. It appeared to be stable and robust. Good and practical way to measure throughput – hop number dependency is FTP transfer. Measurements presented in this paper confirm the theory for collocated nodes: throughput is inversely proportional to number of hops that data has to traverse. Future work may include comparison of experimental results with theoretical mathematical model, additional route hot swap measurements as well as influence of hardware differentiations on chain throughput measurements.

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