Performance Analysis of Routing Protocols in Ad-hoc and Sensor Networking Environments

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***Abstract* — Ad-hoc and sensor networks are becoming an increasingly popular wireless networking concepts lately. This paper analyzes and compares prominent routing schemes in these networking environments. The knowledge obtained can serve users to better understand short range wireless network solutions thus leading to options for implementation in various scenarios. In addition, it should aid researchers develop protocol improvements reliable for the technologies of interest.**

***Keywords* — Ad-hoc networks, Sensor networks, AODV, DSDV, Performance analysis.**

I. Introduction

Variety of wireless solutions with different characteristics in terms of coverage, data rate, network architecture, mobility etc. exist today. The concepts of ad-hoc and sensor networking increasingly emerge as representatives of short range wireless solutions. Moreover, they are also envisioned as access technology enablers in the evolution towards seamless communications [1] and will represent the building blocks for the future unified 4G platform [2].

Short range wireless communication networks are potential cornerstones of future generation communications systems. They serve as a last hop connection to the end users and, lately, as providers of broadband services. Therefore, it is important to know the performance of the short range networks and to test their capabilities through various parameters under different scenarios, especially in a multi-hop and an ad-hoc environment. Different routing schemes (e.g. proactive, reactive, hybrid etc.) emerge as important aspects of the network functionality.

The scope of this paper is to analyze a set of performance parameters in an IEEE 802.11 based (Wi-Fi) network, operating in an ad-hoc mode, and an IEEE 802.15.4 based (ZigBee) network. Two different routing protocol mechanisms are explored, i.e. AODV (Ad hoc On demand Distance Vector) and DSDV (Destination Sequenced Distance Vector), because of their simplicity and performances when implemented in various ad-hoc and sensor networks environments. The paper concentrates on performance analysis of these two protocol schemes in order to better understand the protocol efficiency and flexibility. The basic functionalities of these protocols offer possibilities for further improvements resulting in possible development of more advanced routing schemes as a future work.

The paper is organized as follows. Section II gives a short overview of the technologies of interest as representatives of ad-hoc and sensor networks and briefly explains the protocol mechanisms used in the analysis. Section III elaborates the related work offering parameters used for comparing routing protocols. Section IV describes the simulation scenario and shows the results obtained by simulation in ns-2. Finally, Section V concludes the paper.

II. Technologies & Protocols overview

This section gives a brief overview of the two wireless technologies of interest and the routing protocols used in the simulations.

A. *IEEE 802.11 and IEEE 802.15.4*

The IEEE 802.11 specification is a wireless LAN standard developed by the IEEE (Institute of Electrical and Electronic Engineering) committee in order to specify an "over the air" interface between a wireless client and a base station or an Access Point, as well as among wireless clients [3]. The benefits of this technology in terms of high bit rate make it attractive also for short range communications where a small number of points of attachment can serve many ad-hoc users.

ZigBee is a communication protocol based on the IEEE 802.15.4 standard [4] for low rate energy efficient information exchange. The low power usage allows longer node life with small batteries and the mesh network topology provides high reliability (star and tree topology are also possible). The channel access can be obtained in two modes, i.e. non beacon and beacon mode. There are three types of devices: FFD (Fully Function Device), RFD (Reduced Function Device) and Network Coordinator (NC) that can be used in order to create a network for personal benefit of the users.

B. *AODV and DSDV*

The routing protocols used in short range wireless communications networks are mainly classified in two big groups, proactive and reactive protocols [1]. They perform

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differently depending on the network topology and the underlying radio technology. The proactive routing protocols generate a large number of control messages that can consume almost all of the available bandwidth. This can lead to communication difficulties in large network topologies, especially when there is a high degree of mobility. On the other hand, the reactive protocols establish route only when needed thus creating topology graph when information needs to be transferred with less control messages. However, finding a route through the network graph can be longer with this approach.

The paper assumes the usage of two types of reactive protocols: AODV and DSDV. The purpose of the paper is not to describe the messages they use and the way the routing table "refreshments" are made. Instead, the basic code of the routing protocols implementation is taken and run in an ad-hoc and sensor environment in order to obtain results.

III. RELATED WORK

There are number of papers found in the literature where routing protocols are compared, but mainly under a single technology. Different radios can make the performance evaluation more specific and offer better protocol performance insight through different parameters. For example, [5] shows the average throughput and the average number of hops in the proposed simulation scenario when AODV is used with IEEE 802.11a radio and also plots the packet delay for the optional modulation schemes the standard proposes. The work presented in [6] includes mobility of nodes and researches the packet delivery parameter. This parameter can indicate the quality of the established sessions in the network architecture. In addition, reference [6] shows the routing overhead parameter in different protocol mechanisms in the IEEE 802.11 radio. This parameter gives insight into the protocol ability and flexibility to establish routes in complex topologies where the nodes are mobile. The work done in [7] proposes IEEE 802.15.4 (ZigBee) mesh algorithm and compares it to AODV when there are network topologies with heterogeneity (different types of devices). The performances in terms of delivery ratio are improved with the proposed algorithm. Similar papers can be found where DSDV performance parameters are tested in both technologies though a research with this protocol is rarer. Reference [8] makes performance behavior analysis of different routing protocols for Two Ray Ground and Shadowing radio models. Comparing protocols through different radio models is important for protocol efficiency. As shown, through literature researches mostly concentrate in analyzing protocols performances in one technology and proposing advanced routing schemes, that is protocols improvements for better performances.

This paper compares and analyzes performances of basic protocol mechanisms in different technologies in order to obtain their performance parameters thus giving opportunity for satisfying variety of users preferences (what type of service should be obtained from what type of network in which different routing schemes are implemented). The performance parameters of interest are application oriented and describe the how users can 'see' the protocol from service point of view.

Because of the specific nature of the problem and its complexity number of aspects has to be taken into consideration when building the simulation scenario. These aspects are elaborated in the following section.

IV. SIMULATION ANALYSIS

The simulation analysis in this section was performed in ns-2 [9] as the most prominent ad-hoc networking simulation tool. It is used to compare the behavior of different ad-hoc network characteristics and performances. The basis in all analyzed both for Wi-Fi and ZigBee, is focused on using the same mobility model, same topology, traffic and routing protocols.

The simulation area for the Wi-Fi scenario is defined as a 1000 x 1000 meters square, whereas the simulation area for the ZigBee scenario is also defined as a 50 x 50 meters square. The area in the ZigBee simulations is far smaller than in Wi-Fi because of its short range capacity, i.e. ZigBee has a coverage of only few tens of meters, where Wi-Fi has a maximum coverage of a couple of hundred meters (the IEEE 802.11n version of the standard).

The number of nodes in both simulation scenarios, for Wi-Fi and ZigBee varies from 10 to 60, with an increment of ten. The mobility management model sets the position of the nodes based on a random generator of coordinates. The movement speed and pause are also randomly defined with two parameters, i.e. a mean value (fixed) and a variance of the value. The variance sets the maximum oscillation value from the mean value. The mean values for the speed and pause in Wi-Fi were 10m/s and 10s, with a variance of 1 m/s and 1s, respectively, while in ZigBee the mean values of the speed and pause were 1m/s and 20s, with a variance of 0.1m/s and 0.1s, respectively. The time duration of the simulations has been set to 60 seconds for all scenarios. All of the nodes in the simulations follow the random waypoint mobility model, which is generated before the start of every simulation. Also, the established sessions in the scenarios are variable. Small and large number of sessions is taken into consideration (2 and 10 sessions), where the establishment of the sessions is also random. The traffic used in all simulations was 1 Mbps FTP/TCP.

Three parameters are measured in order to obtain protocol performance information, i.e.:

- *protocol overhead*,
- *end-to-end delay* and
- *TCP packet ratio* of the sessions established.

The routing overhead is actually the ratio between the number of bytes of the routing protocol and the number of useful bytes i.e. TCP bytes. This gives information how the routing protocol performs in terms of loading the network and dynamic topology changes (for example, number of active nodes, mobile nodes, node failure or number of active applications sessions). The end-to-end delay is defined as the average ratio between the aggregate delay and the number of packets that are sent and received. The aggregate delay is the sum of all single packet delay where the single packet delay is defined as the difference between the time when the packet was first sent and the time when the packet reaches its final destination. TCP packet ratio is defined as the ratio between the number of all TCP packets that are received and the number of all TCP packets sent. This parameter gives information about the network capacity, i.e. the technology characteristics, in dependence of the number of active application sessions, number of active nodes etc.

Fig. 1 shows the simulation results for protocol overhead of DSDV and AODV in a Wi-Fi environment. DSDV overhead is larger for small number of sessions while AODV overhead, despite its regularity, shows greater difference between the curves for small and large number of sessions. Moreover, Fig. 1 depicts that both routing protocols are well tailored for scenarios with maximum 40 nodes. However, the routing overhead in scenarios with larger number of nodes can have very high values leading to potential problems regarding energy efficiency, real-time traffic handling and application throughput demands. In scenarios with high node density, AODV overhead has a slightly smaller values compared with DSDV overhead, which can be crucial performance parameter in choosing routing protocol for ad-hoc or sensor networks dimensioned to optimize network capacity.

The routing overhead parameter tested in ZigBee results in overhead increase with the increase of the number of sessions and/or the increase of the number of nodes.

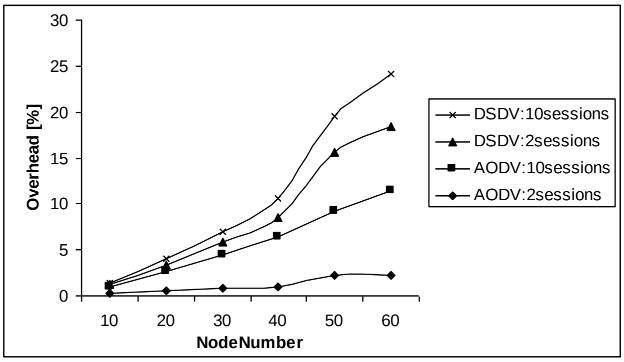
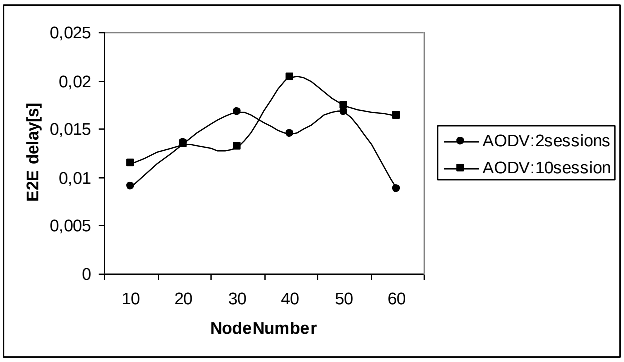


Fig. 1. AODV and DSDV overhead for different number of sessions in Wi-Fi

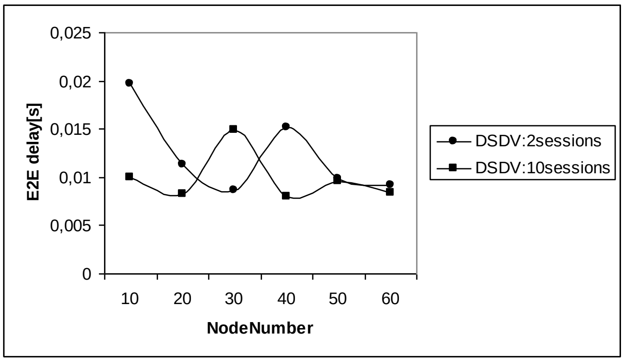
Fig. 2 shows the simulation results for end-to-end delay in ZigBee environment for the AODV (a) and DSDV (b). It is evident that the curves for small and large number of sessions differ greatly. Also, the DSDV end-to-end delay has an irregular form for different number of sessions depending on the node number. For a network with small number of nodes, a minimum delay is experienced with large number of sessions established. However, the opposite happens when there are small number of sessions in a topology with small nodes number. AODV overhead curves for small and large number of sessions are relatively close as both increase with the increase of the node number.

As shown in Fig. 2, the DSDV routing protocol has a tendency to oscillate around a constant mean value regardless of the number of nodes, while AODV oscillates around a mean value that is gradually increasing with the increase of the number of nodes. It is apparent that DSDV performs more independently as the number of nodes and the number of sessions increase in the network. As a result, DSDV gives better end-to-end delay performance than AODV. Another thing than can be concluded is that as the number of nodes grows (60 or more), the end-to-end delay is decreasing due to the fact that area is better covered with more nodes and probalility of route establishment failure is very small.

On the other hand, the end-to-end delay in Wi-Fi is higher for large number of sessions and yields relatively constant values as the number of nodes increases (not shown in Fig. 2). This can lead to significant performance degradation in high density scenarios and implementation of ad-hoc network for real-time demanding traffic can become very difficult.



(a)

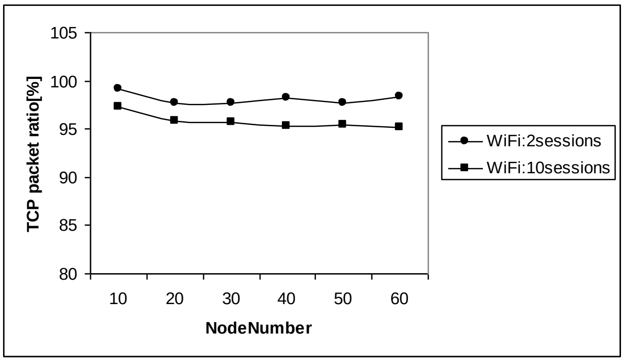


(b)

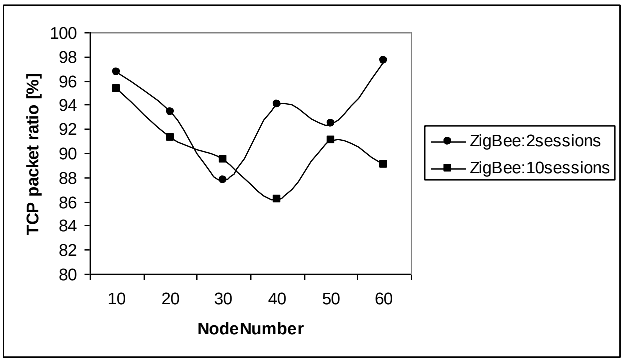
Fig. 2 AODV (a) and DSDV (b) end-to-end delay overhead for different number of sessions in ZigBee

Fig. 3 shows the simulation results for AODV packet ratio in Wi-Fi (a) and in ZigBee (b). DSDV packet ratio is not shown since the simulation platform does not allow an analysis of this parameter. The packet ratio parametar, when using AODV protocol, shows the properties of the both technologies. Namely, Wi-Fi is more stable so the packet ratio has higher and more constant values for different number of nodes and TCP sessions. In contrast, ZigBee introduces lower and more variable values for different number nodes and sessions. This is due to the fact that TCP throughput is more influenced of the network topology. The number of sessions also influences the packet ratio values as large number of sessions yield smaller packet ratio independently of the technology used.

Fig. 3 also shows that for networks with large number of nodes, the number of sessions (traffic load) has a significant influence on the packet ratio. Large number of sessions established in the network can cause dramatic losses. The analysis of the ratio parametar gives insight of the network stability thus application that requires a lossless transfer can be handled when there are high packet ratio values.



(a)



(b)

Fig. 3. TCP packet ratio with AODV routing schemes for different number of sessions in Wi-Fi(a) and ZigBee(b)

The analysis in this section gives an insight into how the routing protocol implemented in a proposed network scenario (node number, active sessions, random waypoint mobility) performs. Low delay values will indicate that services with high delay constraints can be delivered. Packet ratio directly influences the network capacity for exchanging information between the nodes for services that require reliable transfer through the network nodes from source to destination. The overhead parametar describing the ability of the protocol to handle scenarios with dynamical topology changes indicate how users with high mobility should be served. Knowledge of these parameters functions can help in numerous problems that can occur in ad-hoc and sensor networks.

V. CONCLUSIONS

The ad hoc concept of networking and emerging sensor networks are the future of the wireless communications systems due to their user centric approach. This means that users can get the demanded service in any place at any time with satisfying quality. Routing is an important aspect for delivering the service to end users. Different routing mechanisms show different properties in wireless environment, but also one routing scheme behaves differently for different wireless technology.

The aim of the paper was to analyze different performances of two routing protocols in two wireless technologies as representatives of ad hoc and sensor concept of networking.

The AODV protocol shows better performances for the overhead percentage in contrast to DSDV when tested in Wi-Fi environment. On the other hand, DSDV yields better delay characteristics when tested in ZigBee environment. The packet delay ratio is tested in different environments due to simulation possibilities only with AODV routing protocol and its clear when AODV scheme is used, Wi-Fi is better technology for services that require lossless transfer.

Future work may include analysis of various improvements of the proposed protocols and analyzing different parameters under different scenarios in various wireless environments.

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