Comparing Routing Protocols

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***Abstract*— A routing protocol disseminates information for route selection between any two nodes on a network and thus provides the ground for sending data (packets) through the network. Routing protocols are used in a wide range of application areas in various types of networks, such as Local Area Networks (LAN), Mobile Ad hoc Networks (MANETs) or Wireless Mesh Networks (WMN). Due to the application diversity, different protocols have been developed. For instance in the case of WMNs, there are reactive protocols, such as AODV, and proactive protocols, such as OLSR. These protocols have been already implemented and deployed. However, it is unclear which protocol should be used in certain circumstances: Could we assume that AODV performs better than OLSR in case of reduced network traffic? Is OLSR better than AODV when considering mobile networks? To answer these questions systematically, we aim at formally defining properties that can be used as metrics (measurements) for routing protocols. To evaluate the measurements, we focus on comparing AODV and OLSR protocols.**

I. Introduction

Wireless technologies are on the rise, from the more obvious laptops and smart phones in use everywhere, to sensor networks generating large amounts of data on weather, terrain, etc, to envisioned electrical cars being charged wirelessly. These technologies will always be subject to various types of failures and attacks and thus, need to be reliable and flexible, to demonstrate resilience to adversities. In our work, we focus on contemporary wireless technologies, in particular Wireless Mesh Networks (WMNs).

WMNs are self-organising and self-healing wireless multi-hop networks which are supposed to provide support for broadband communication with no need for any wired infrastructure. As a consequence, they provide the benefit of low-cost and rapid network deployment. Such networks have gained popularity and are vastly applied in a wide range of applications, such as communication, smart electrical grids, emergency response networks, wireless video surveillance, firefighting, etc. One of the significant features of such networks is that communication is often truly distributed without depending on any central entity (router) for coordination; importantly, a certain set of requirements on networks must always be satisfied: if not, catastrophic results can occur.

Another important feature of such networks is that the network topology can change easily. For instance, nodes might just fail to work in case of natural disasters; or nodes such as laptops and mobile phones can move within the network or even enter or leave a network in case of telecommunication systems. Hence, routes between source and destination nodes are usually not stable over time; one of the primary objectives of WMN routing protocols is to provide for such instability.

Routing protocols have to provide communication routes between different nodes; as this is a quite fundamental role, routing protocols determine the reliability and performance of the network. A routing protocol determines how nodes communicate with each other in a network by disseminating information enabling them to select routes. In this way, network nodes are able to send data packets to arbitrary (previously unknown) destinations in the network.

Routing protocols of WMNs are divided into two main categories: reactive and proactive routing protocols. In proactive protocols, routing toward nodes is always kept up-to-date by distributing control messages throughout the network, while reactive protocols build and update their routing information on demand. An instance of a reactive routing protocol is Ad hoc On-Demand Distance Vector (AODV) and an example of proactive one is Optimised Link State Routing (OLSR) protocol. Both of these protocols are identified as standard ad-hoc routing protocols by the IETF MANET working group[1].

These protocols have been implemented and deployed by common methods used for evaluating and validating network protocols (test-bed experiments and simulation in 'living lab' conditions). Such an analysis is usually restricted to very few topologies and global properties such as overall throughput or message delay. Moreover, these methods are typically used for testing implementations rather than design specifications [1].

In this setting, it is unclear which protocol should be used in certain circumstances: Could we assume that AODV performs better than OLSR in case of reduced network traffic? Is OLSR better than AODV when considering mobile networks? To answer these questions systematically, we aim at formally defining properties that can be used as metrics (measurements) for routing protocols. To evaluate the measurements, we focus on comparing AODV and OLSR protocols.

For this, we need certain formal specifications of the protocols making formal comparison feasible w.r.t. different performance metrics (requirements). Formal methods provide valuable tools for the design, evaluation, and verification of WMN routing protocols; they complement alternatives such as test-bed experiments and simulation. These methods have a great potential on improving the correctness and precision of design and development, as they produce reliable results. Formal methods allow the formal specification of routing protocols and the verification of the desired behaviour by applying mathematics and logics [2]. In this way, stronger and more general assurance about protocol behaviour and properties can be achieved.

[1]http://datatracker.ietf.org/wg/manet/charter/

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Currently, we have the formal specifications of AODV [3] and [4] and OLSR [5], and it is possible to even translate them into other formal languages. For instance, we can translate process algebra to timed-automata or to some other specification languages. To make the comparison possible, we have to define and classify different routing metrics used for performance analysis. Such metrics (requirements) can be categorised as following:

- *Overhead*
- *Delay*
- *Route quality*
- *Route establishment*
- *Packet delivery/loss*
- *Optimal route finding*
- *Recovery time*

Here, *Overhead* is related to the number of extra messages in the network (traffic in the network). *Delay* is concerned with the time needed for a data packet to be delivered at the destination node. *Route quality* clarifies how good a route is in terms of the number of delivered packets via that route. *Route establishment* shows the time needed for acquiring the information about the other nodes (time needed for initialisation). *Packet delivery/loss* considers the number of delivered/lost packets. *Optimal route finding* checks if optimal routes are found. *Recovery time* calculates the time needed for the protocol to be recovered after any link breakage (finding new routes).

We should add here that all of these metrics (properties) need to be analysed and to be compared in both mobile and static networks. There might be the possibility that for instance OLSR yields less delay compared to AODV when delivering a packet, however it might cause more network traffic.

There are several studies that compare different routing protocols such as OLSR and AODV using simulation techniques and test-bed experiments [6] and [7]. However to the best of our knowledge, there is no study comparing these protocols formally, by applying formal techniques. In spite of a good overview provided by such techniques (simulation and test-bed experiments), these techniques are not able to investigate and compare key safety properties of such protocols in a comprehensive manner. As a consequence, our contribution in this work consists of formally defining properties that can be used as measurements for routing protocols and providing a systematic and rigorous comparison of OLSR and AODV protocols to be usable in safety critical systems (which protocol outperforms the other one in different circumstances).

We proceed as follows. In Section II, we overview the OLSR [8] and AODV [9] routing protocols based on their specifications. We describe the methodologies that we envision using in Section III. Related work is reviewed in Section IV.

II. OLSR AND AODV

In this section we overview only the main mechanisms of OLSR and AODV and we abstract from most details such as sequence numbers, etc.

A. Optimised Link State Routing

The Optimised Link State Routing (OLSR) protocol [8] is one of the proactive routing protocols particularly tailored for WMNs and Mobile Ad hoc Networks (MANETs). The proactive nature of OLSR allows to have the routes immediately available when needed (each node has the information about all other nodes in the network). This protocol exchanges control messages, namely *HELLO* and *TC (Topology Control)* messages every 2 and 5 seconds respectively, aiming at establishing routes to previously unknown destinations, updating routing information about known destinations, and monitoring the network topology.

OLSR protocol reduces flooding of control messages in the network by selecting so-called MultiPoint Relays (MPRs). Each node selects a set of such neighbour nodes as MPRs; this set links to all of the node's two-hop neighbours.

Upon receiving *HELLO* messages from direct neighbours, each node chooses its MPRs and selected MPRs learn about their MPR selectors (those nodes that have selected them as an MPR). Afterwards, MPRs broadcast *TC* messages for building and refreshing (updating) topological information. Such messages can be forwarded (transmitted) on more than one wireless link by intermediate MPRs.

When a node receives control messages (*HELLO* and *TC*) from other nodes, it updates its routing table for the originator of the received message. After broadcasting and forwarding control messages via nodes through the network, routes to all possible destinations (different nodes in the network) are assumed to be established and nodes should have the required information about all the other nodes in the network. As a consequence, nodes are able to select paths (routes) to send and deliver data packets to arbitrary destination nodes.

B. Ad hoc On-Demand Distance Vector

The Ad hoc On-Demand Distance Vector (AODV) [9] is one of the reactive routing protocols used in WMNs. It is also designed for use by mobile nodes in ad hoc networks. AODV adapts to dynamic link conditions and determines routes to destinations within the ad hoc network. It allows nodes to acquire routes quickly for new destination nodes and is not based on maintaining routes to destinations which are not in active communication.

AODV exchanges three types of messages, namely *Route Requests (RREQs)*, *Route Replies (RREPs)*, and *Route Errors (RERRs)*. When a route from the source node to a new destination node is required (for instance, a packet from a source node must be delivered at the destination node), the source node broadcasts a *RREQ* aiming at finding a route to the destination. A route can be found if the *RREQ* reaches the destination node itself, or an intermediate node having a fresh route to the destination node. A fresh route means a valid route entry for the destination whose associated sequence number is at least as large as the one in the *RREQ*. Then, the route is known by unicasting a *RREP* messages back to the source of *RREQ*. *RREQ* receiver caches a route back to the source of the request in a way that the *RREP* can be unicast from the destination along the path to the source node, or from any intermediate nodes satisfying the request.

Nodes in the network keep track of the link status of next hops in active routes. In case a link in an active route breaks, a *RERR* messages is sent to other nodes declaring the link breakage. The *RERR* contains the information about those destinations that are no longer reachable via the broken link. All of the information received from different nodes is stored in the routing table of every node so that a source node would be able to deliver data packets to destination nodes.

III. Methodologies

Currently, we have the formal specifications of OLSR as networks of timed automata [5] and AODV in both timed automata and process algebra (see [4] and [3]). So, it is possible to compare these protocols w.r.t. some of their requirement (properties) related to timing variables mentioned in Section I. However for the rest of properties, we need to have the process algebraic specification of OLSR to make the comparison feasible. In addition, for those properties which have to be translated to some other formal languages, we must provide the corresponding formal specifications for rigorous analysis.

So far in [5], we modelled OLSR as a composition of two timed automata precisely modelling the core functionality of this protocol and we verified our model for the following properties (in small networks up to 5 nodes):

- Route establishment
- Packet delivery
- Optimal route finding
- Recovery time

Since the model checking technique considers only a finite number of specific network scenarios, it is not generic enough and the the proofs cannot hold for all possible network scenarios (large networks cannot be verified by applying model checking because of the problem of state space explosion).

AODV protocol was formally modelled by process algebra [4] and timed automata [3] to verify the following properties:

- Route establishment
- Optimal route finding
- Loop freedom

A first step in our research is to verify recovery time property for the timed automata model of AODV. A second step consists of creating model of OLSR, to compare with the AODV properties listed above.

In a nutshell, we aim at providing specifications (metrics) which are generic and also expressing proofs which hold for any possible network scenario. None of the experimental protocol evaluation approaches can deliver this high degree of assurance about protocol behaviour. A third step consists in verifying some other properties from the list in Section I, to get a better understanding of these protocols. Following these steps, a systematic comparison needs to take place, to determine OLSR and AODV's strengths and weaknesses in varied scenarios.

IV. Related Work

While performance analysis of network protocols is not a new research topic, attempts to formal analysis and comparing of routing protocols are still rather new and remain a challenging task. In the following, we overview some research related to comparison of routing protocols using simulation techniques. However, to the best of our knowledge, this study is the first dedicated to formally defining properties that can be used as measurements for routing protocols and providing a systematic and rigorous comparison of OLSR and AODV protocols using formal techniques.

Huhtonen [10] compares OLSR and AODV in terms of performance, scalability, and resource usage. This study shows that AODV performs better than OLSR in networks with static traffic, and also due to using fewer resources, AODV can be applied in resource critical applications. OLSR outperforms AODV in networks with high density and highly sporadic traffic and also scalability of both protocols is restricted to their proactive and reactive features.

Singh and Mahajan [6] studies the comparison of OLSR and AODV w.r.t. delay, network load and throughput using Opnet simulator. The result of their work shows that OLSR performs better in terms of network load and throughput and AODV outperforms OLSR when considering delay as the criteria for comparison.

Santhamurthy [7] compares AODV, OLSR and Temporary Ordered Routing Algorithm (TORA) protocols in MANETs. This study investigates the performance of these routing protocols in terms of end-to-end delay, packet delivery ratio, path optimality, routing overhead. It indicates that in networks with low mobility, the end-to-end delay of OLSR and TORA is less than AODV, the packet delivery ratio of all protocols is high, the route overhead of OLSR and AODV is less than TORA, and OLSR and TORA are able to find more optimal paths than AODV. In networks with high mobility, the end-to-end delay of OLSR is less than AODV and TORA, the packet delivery ration of TORA is less than OLSR and AODV, the route overhead of all protocols is in the average, and OLSR and TORA can select more optimal paths than AODV.

Although all of these studies make a comparison between OLSR and AODV, none of them can deliver a high degree of assurance about protocol behaviour since they consider only a finite number of specific scenarios.

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