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QoS Aware Component-Based Routing in Resource-Constrained Wireless Multi-Hop Networks

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***Abstract*—With an increasing number of wireless devices available, there is a tremendous need for designing new efficient protocols, which take into account resource constraints and at the same time provide adequate Quality of Service (QoS) performance guarantees (e.g. throughput, latency etc.). Most wireless protocols currently used perform well under specific environmental conditions or in particular applications. In this work, we propose a novel methodology for designing routing protocols for resource-constrained wireless multi-hop networks by separating the protocol into distinct components, which specify particular functionalities. Different QoS requirements can be guaranteed by configuring the different components without the need to modify or develop the protocol from scratch. An initial study for energy-constrained environments indicated that our approach is effective. In our ongoing work we consider adversarial environments and we develop techniques to mitigate network-layer attacks. Finally we are investigating the design of a decision-theoretic module for dynamic protocol configuration.**

***Keywords*- QoS performance, Routing, multi-hop networks**

I. Introduction

Wireless communication systems without centralized infrastructure have gained popularity in the research community in the form of Mobile Ad-Hoc Networks (MANETs), sensor networks, body-area networks and in general the Internet of Things (IoT) architecture. Such networks have a wide range of applications from resilient communications and infrastructure monitoring, to crowdsourcing and distributed processing of data.

A major concern in this type of networks is that they suffer from network resource constraints, such as battery power, bandwidth etc. These constraints should be taken into consideration in designing and implementing network protocols. Network protocols should also be able to adapt to different environmental conditions in order to attain Quality of Service (QoS) performance guarantees.

Routing is a fundamental building block that significantly affects network performance by selecting appropriate and QoS aware communication paths to the destination nodes. The routing protocol contains a variety of different functionalities, from neighbor discovery to path selection, which significantly affect its operation and performance. These functionalities can be separated and considered as individual modules, also defined as components of the protocol. Dynamic configuration of the individual components is our key enabling idea for satisfying performance requirements under different environmental conditions.

The motivation for our work stems from conventional protocol design methodologies, as well as from the lack of adaptability and the orchestration of existing routing protocols under heterogenous networks and different QoS requirements. The primary incentive is that there is no systematic way for describing the different functionalities of routing protocols and the way that different protocol components are interconnected. In addition, most of the routing protocols that are being proposed are monolithic, designed and implemented from scratch in order to attain specific performance guarantees. Hence, their performance improves only under specific environmental conditions. Finally, as far as we are concerned there is not a general way to dynamically configure existing routing protocols to adapt to different environmental conditions, e.g. different network dynamics or malicious environments, or QoS requirements per traffic flow or application.

In this work, we propose a novel systematic way for QoS aware routing protocol design. It is based on abstracting protocols into components based on their functionalities. This allows *modularity* in protocol design and *reusability* of existing components across current and future protocols of the same class. Our vision is to create a library of components that can easily be plugged into each protocol with minor modifications, and to configure the protocol's functionality according to environmental conditions in order to increase the QoS performance. In addition, we are working towards designing a decision-theoretic module that would ideally initiate protocol configuration by taking into account local measurements. We have already illustrated in an initial study in energy-constrained environments that our approach is feasible. Our research work focuses on applying these principles for designing efficient protocols in adversarial environments, where we have to tackle the consequences of attacks on network performance. Our approach is to design lightweight and reusable techniques that aim to configure misbehaving components (functionalities) of the protocol.

The rest of the paper is organized as follows. In Section II we shortly describe the related work. In Section III we describe our approach and the challenges for this work. We present some preliminary results in Section IV and finally some future directions in Section V.

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II. Related Work

The approach of component-based design of wireless routing protocols was first proposed by Baras and He in [1], where the authors introduced a general decomposition of reactive routing protocols. In addition, they developed a methodology for detecting weak components in terms of performance in order to replace them with different appropriate components. An initial decomposition of proactive routing protocols was introduced in [2] and used OLSR as a case study. The authors analyzed the operation of three of the fundamental building blocks. In addition, they focused on the Neighborhood Discovery Component (NDC) and provided a methodology for design and modification of this component in order to achieve reliable performance.

CONFab, a software framework for component based optimization of wireless sensor networks protocol stacks is proposed in [3]. The authors treated the protocol stacks as a collection of interdependent configurable components. Based on a given scenario and the desired performance metrics the framework suggested suitable protocol stacks and selection of parameters. Furthermore, a component-based architecture for power-efficient MAC protocol development in wireless sensor networks, called MAC Layer Architecture (MLA), is presented in [4]. The authors defined and implemented a set of fundamental components for MAC layer protocols in wireless sensor networks. These components are optimized and reusable across different protocols as they implement a set of common features shared by existing MAC protocols.

A declarative policy-based approach for adaptable extensible MANET protocols is presented in [5]. The authors introduce the design of composite protocols using two mechanisms: policy-driven hybrid protocols and component-based routing. Finally, Anwer et. al recently proposed Slick [6], a prototypical control plane for network middleboxes. This framework supports dynamic reconfiguration of network functions according to the traffic demands and the performance guarantees. It is an example of deploying efficient network policies in specific parts of wireline networks. Our work aims at enabling a similar-type of network management in a wireless multi-hop environment.

III. Proposed Approach and Challenges

Our approach for enabling QoS aware routing is based on separating routing protocols into fundamental building blocks called protocol components, and on optimizing each of them according to the objective and the network conditions. Components can be considered basic modules of protocols depending on their distinct common functionalities. Thus, we should ideally have a library of protocol components for various classes of routing layer protocols for wireless multi-hop networks that can be easily reused across protocols of the same class with minor modifications. A detailed decomposition of proactive routing protocols was presented in [7] and can be shown in Fig. 1. In this diagram, we can observe the distinct protocol functionalities and their interconnection.

Different routing protocols can be dynamically customized based on the different QoS demands. For example, we enable different modifications of the components when the application requires high packet delivery ratio and when it is time critical (requires low latency). In order to adapt to different requirements and environmental conditions, we propose a decision module that is executed in every node of the network. A module detects the current network state and decides among a set of actions on protocol configuration. Network state consists of network characteristics, such as number of neighbors, network dynamics etc. The set of actions comprise of various configurations of the protocol components, which are proven to attain good performance for certain network conditions.

In our work, we examine networks with malicious nodes. These nodes are deploying different types of network layer attacks, which aim to either manipulate routing procedures or to influence packet delivery. Examples of the attacks that we examine are blackhole/greyhole, wormhole and packet dropping attacks. These attacks influence the performance of particular protocol components and lead to performance degradation in terms of packet delivery ratio and end-to-end delay, because they affect topology formation and route selection. The objective of our approach is to modify these components by designing lightweight mitigation techniques.

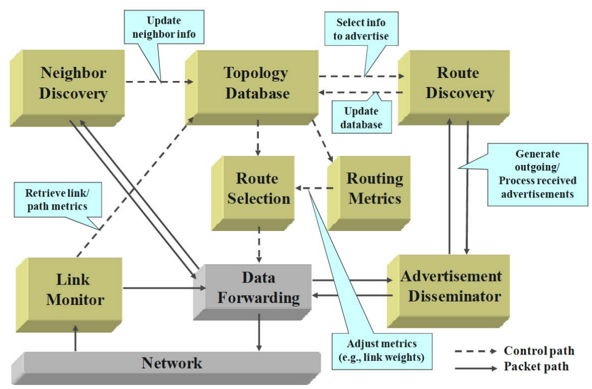
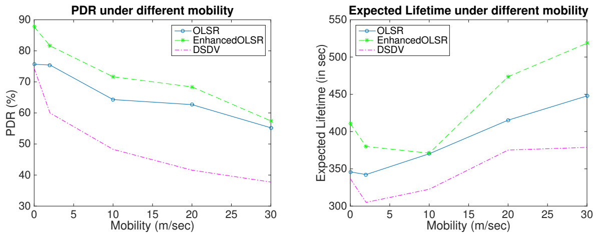


Fig. 1: Decomposition of Proactive Routing Protocols into Components

The *challenges* that we want to address with our proposed work are:

- Are we able to adjust routing protocol behavior with minor modifications for different QoS requirements? For example, different applications and their related network traffic targets different performance objectives. This idea is similar to applying Software-Defined Networking principles in the context of wireless networks.
- How can we design a decision making module running at each node to appropriately configure network protocols? This module will incorporate a monitoring system and will take decisions based on the collected network measurements. The collected network measurements will define the state of our neighborhood and our module will take the appropriate actions to modify the routing protocol. We also want to investigate this module in case that we experience network instabilities.
- What are some possible lightweight component-oriented mitigation techniques that can dynamically change the behavior of our protocol against possible



(a) PDR comparison under different mobility

(b) Network Lifetime under different mobility

Fig. 2: PDR and Lifetime Performance

attacks? In this particular scenario, we need to investigate what is the cost of assuring security in terms of QoS performance. There is a tradeoff between security and QoS guarantees, since the use of encryption schemes significantly impacts processing delay and energy consumption in the wireless devices.

IV. Preliminary Results

In this section, we refer to some preliminary results of our approach under different environmental conditions. In our previous work in [7] we propose a reusable Routing Metrics protocol component in the case that our objective is to save energy across the network to prolong network lifetime. In this context, we introduce a new energy-aware routing metric that can be used across different existing routing protocols. We conducted an initial performance evaluation using OLSR [8] module of NS-3 simulator [9] as our baseline. In this set of experiments, we compare performance of Enhanced OLSR with standard OLSR and DSDV [10] protocols, which are two widely used and deployed proactive routing protocols. The experimental results presented in [7] and shown in Fig. 2, indicate significant improvement in terms of lifetime and packet delivery ratio (PDR) for the Enhanced OLSR case in energy-constrained environments under different mobility scenarios. We should also mention that network lifetime has several definitions, such that the time until one node gets depleted or a percentage of nodes get depleted, the time until we encounter network disconnectivity etc. For the initial performance evaluation we take into consideration the most widely used definition for network lifetime, which is defined as the time until the first node is completely depleted from energy.

In our ongoing research work, we consider adversarial wireless networks, where some of the nodes misbehave and release network layer attacks to manipulate routing protocol operation (control traffic) and disrupt data packet delivery (data traffic). These attacks affect significantly network performance, since our initial investigation showed that their deployment degrades packet delivery ratio (PDR) and increases latency. In this case, we have designed efficient component-related mitigation techniques that enhance protocol operation and recover network performance under the presence of attacks. The novel mitigation techniques are lightweight and reusable as they can be used across multiple existing routing protocols of the same class.

V. Conclusion and Future Work

In this work, we presented a novel constructive methodology for QoS aware routing in resource-constrained wireless multi-hop networks. It is based on defining protocol components, which are fundamental building modules of different classes of routing protocols. Different configuration of these protocol components has an impact in QoS performance (packet delivery, latency, network lifetime etc). Therefore, the vision of our approach is to be able to adjust our protocol functionalities based on the QoS objective of our application and the network conditions.

As part of our ongoing and future work, we are investigating malicious environments, which suffer from various network layer attacks. Our goal is to configure particular protocol components to recover network performance. In this particular scenario, we would like to investigate what is the cost for security in terms of some QoS parameters, such as delay and energy consumption, when the protocols are applied to lightweight devices with small processing and battery power.

Acknowledgment

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