SHORT TERM SCIENTIFIC MISSION (STSM) SCIENTIFIC REPORT

This report is submitted for approval by the STSM applicant to the STSM coordinator

Action number: CA15127 (RECODIS)
STSM title: WSN Optimization Model Accounting For Network Lifetime Maximization
STSM start and end date: 15/09/2019 to 29/09/2019
Grantee name: Artur Tomaszewski

PURPOSE OF THE STSM:

The purpose of the STSM was to extend the research presented in M. Pióro, A. Tomaszewski, A. Capone's paper "Maximization of multicast periodic traffic throughput in multi-hop wireless networks with broadcast transmissions" (*Ad Hoc Networks*, vol. 77, 2018, pp. 119-142) [1], in order to include resilience to adverse weather conditions into optimization modelling of wireless mesh networks (WMN) that use broadcast radio transmissions and carry multicast packet traffic (such networks will be referred to as WMN/radio). The assumed application context was that of sensor networks collecting and disseminating measurement data, which was considered in another research – presented in E. Fitzgerald, M. Pióro, A. Tomaszewski's paper "Energy-optimal data aggregation and dissemination for the Internet of Things" (*IEEE Internet of Things Journal*, vol. 5, no. 2, 2018, pp. 955-969) [2].

The goal was to extend the basic network optimization model addressing a real-world situation of sensor networks that operate in an open area and are affected by adverse weather conditions. The augmented model should account, in particular, for the changes in the availability of sensor nodes, variations of radio transmission conditions, and fluctuations of energy/battery usage. The optimization of routing and transmission schemes should provide for least unperturbed collection and dissemination of measurement data and maximization of the network lifetime.

DESCRIPTION OF WORK CARRIED OUT DURING THE STSMS

It is assumed that the network operates in the TDMA mode [1]. There is a TDMA frame that is common for the entire network. The frame consists of a number of timeslots with the same duration. The network is supposed to carry streams of data packets. During each frame a given number of packets are generated at the source node of the stream. It is assumed that the data is multicast to multiple nodes – the packets generated at the source node must reach a number of destination nodes of the stream (potentially, not all of them; this is explained in [2]). In every timeslot a given number (subset) of nodes are transmitting data using broadcast transmission; in a single timeslot the node transmits packets from the same stream. The data transmitted by a node is received at all those nodes at which the received signal is strong enough compared to the interfering signals that are simultaneously broadcasted from the other transmitting nodes (the SINR value is below the given threshold). How to design the so-called compatible sets of transmitting nodes and links, which are used in the time-slots of the transmission frame was proposed in [1].

The first step of the STSM research was to model the impact of weather conditions on the availability of sensor network nodes, radio transmission quality, and energy usage. The basic model was extended with the notion of uncertainty states representing unavailability of given nodes, degradation of transmission quality of given nodes, and increased battery usage of given nodes. The extended problem of multistate design was then defined.

The second step was to analyze the problem of packet routing. First, it was analyzed how to model local rerouting of packets with packet tagging, which allows for avoiding centralized management of the network and complex state control (in particular, disseminating state-related information). The problem of designing primary and multiple backup paths of consecutive levels, taking into account the assumed network states, was formulated and the procedure of solving the problem with path generation was formalized by defining the master and pricing problems.

Then it was observed that the multiple routing paths result naturally from and are an inherent mechanism of the broadcast transmission of the radio nodes – the node transmits the packet simultaneously on a number of links to a number of neighboring nodes. The multipath routing effect is even more pronounced in the considered context of disseminating measurement results due the assumed multicast nature of traffic – the source node of the stream sends the data packet to multiple destination nodes on a number of (partly overlapping) paths. Thus, it was analyzed how to use broadcast transmission and multicast traffic to effectively reach destination nodes on multiple independent paths, increasing network resiliency. The problem of designing optimal multiple routes to destination nodes was then formulated; the model is considerably different from the routing model of the basic problem, where the paths form a multicast routing tree, which is routed at the source node of the stream and reaches each destination node with a single path – it is no longer true. The goal of the optimization is to provide high diversity of routes while not allowing for excessive link capacity usage. And the particular issue of the modelling is the capacity usage calculation.

The third step was to analyze the problem of the transmission scheme design. The problem of optimizing compatible sets was reconsidered with the requirement of sustainable data delivery. The objective of the compatible sets optimization was now to maximize network lifetime by minimizing energy usage at the nodes and providing equal or fair battery depletion rate at different nodes. The objective was achieved at the overall network design level (the master problem formulation), taking into account the assumed network states, and at the level of designing a single compatible set (the pricing problem formulation), taking into account the relation between the signal power and energy/battery usage, the modulation and coding scheme, the radio transmission conditions, and the interference and SINR value.

DESCRIPTION OF THE MAIN RESULTS OBTAINED

The main result of the described STSM is a set of extensions of the basic WMN/radio optimization model that provide for the design of networks resilient to adverse weather conditions. The resulting models are mixed-integer programming (MIP) problem formulations of multi-state traffic routing and transmission scheduling design with the objective of providing for unperturbed collection and dissemination of measurement data and maximization of the network lifetime. The MIP models encompass master problems with appropriate objective functions and the accompanying path and compatible set generation procedures with appropriate pricing problems.

FUTURE COLLABORATIONS (if applicable)

The collaboration of Prof. Artur Tomaszewski (the STSM applicant) with MobiMESH will continue, with further visits planned using other than RECODIS financing means.