High Throughput Multicast Routing Metrics in Wireless Mesh Networks

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***Abstract*— The stationary nature of nodes in a mesh network has shifted the main design goal of routing protocols from maintaining connectivity between source and destination nodes to finding high-throughput paths between them. In recent years, numerous link-quality-based routing metrics have been proposed for choosing high-throughput paths for unicast protocols. In this paper we study routing metrics for high-throughput tree or mesh construction in routing protocols. A new localized quality of service (QoS) routing protocol for wireless sensor networks (WSN) is proposed in this paper. It is based on differentiating QoS requirements according to the data type, which enables to provide several and customized QoS metrics for each traffic category. With each packet, the protocol attempts to fulfill the required data-related QoS metric(s) while considering power efficiency. For link quality estimation, the protocol employs distributed, memory and computation efficient mechanisms. It uses a multisink single-path approach to increase reliability. Extensive simulation study with scenarios of 900 nodes shows the proposed protocol outperforms all comparable state-of-the-art QoS and localized routing protocols. Moreover, the protocol has been implemented on sensor motes and tested in a sensor network testbed. Adapt certain routing metrics for unicast for high-throughput multicast routing and propose new ones not previously used for high-throughput. The performance improvement achieved by using different link-quality-based routing metrics via extensive simulation and experiments on a mesh network testbed, using ODMRP as a representative multicast protocol. Our tested experiment results show that ODMRP enhanced with link quality routing metrics can achieve up to 17.5% throughput improvement as compared to the original ODMRP.**

***Keywords*— QoS,ODMRP,ACK,WSN,MAC,TDMA**

I. INTRODUCTION

MANY applications of wireless sensor networks (WSN), such as vehicular and biomedical, have diverse data traffic with different quality of service (QoS) requirements. This paper focuses on these applications, for which it proposes a localized QoS routing protocol. Traffic differentiation, while simultaneously considering latency, reliability, residual energy, and transmission power in a localized way represents the key features of our contribution. We consider a general scenario typical for many of the targeted WSN applications, where sensors collect different kinds of data and transmit them toward fixed sinks via other sensors in a multichip, ad hoc paradigm. We define two kinds of sinks; primary sink and secondary sink, to which a separate copy of each message that requires high reliability is sent. A typical example of such a scenario is patient monitoring in a hospital room, where different health parameters are to be captured and forwarded to health care servers accessible by the medical staff. Traffic is diverse and may have different QoS requirements, depending on the monitored parameter and its value, the patient health situation, the patient context, e.g., regular monitoring versus monitoring in operating room, etc. Duplication toward a secondary sink may be useful if high reliability is required.

Three different classes of QoS requirements are used in the proposed protocol: 1) energy efficiency (including both residual energy and the required transmission power), 2) reliability, and 3) latency. The first requirement is traffic unrelated, contrary to the other ones. It can be viewed as application-related QoS metric that must be taken into account for all types of traffic, since ensuring a long network lifetime is essential for all applications Wireless sensor networks (WSNs) have been utilized in many applications as both a connectivity infrastructure and a distributed data generation network due to their ubiquitous and flexible nature. Increasingly, a large number of WSN applications require real-time quality of service (Quos) guarantees. Such QoS requirements usually depend on two common parameters: timing and reliability. The resource constraints of WSNs, however, limit the extent to which these requirements can be guaranteed. Furthermore, the random effects of the wireless channel prohibit the development of strict QoS guarantees in these multi-hop networks. Consequently, a probabilistic analysis of QoS guarantees is essential to address both timing and reliability requirements. In this work, we focus on the probability distribution of the end-to-end delay in WSNs. Characterization of the end-to-end delay distribution is fundamental for real-time communication applications with probabilistic QoS guarantees. Indeed, the cumulative distribution function (cdf) of the delay for a given deadline can be used as a probabilistic metric for reliability and timeliness. Characterizing delay in distributed systems has been investigated in different contexts. Recent work has analyzed the latency performance of WSNs in terms of its first order statistics, i.e., the mean and the variance.However, complex and cross-layer interactions in multihop WSNs prevent complete characterization of the delay through only the mean and variance measures. Several efforts have been made to provide probabilistic bounds on delay. As an example, the concept of Network Calculus has been extended to derive probabilistic bounds for delay through worst case analysis. However, because of the randomness in wireless communication and the low power nature of the communication links in WSNs, these worst case bounds cannot capture the stochastic behavior of end-to-end delay. Moreover, work on real-time queueing theory providesstochastic models for unreliable networks.

However, these models consider heavy traffic rate, e.g., saturated traffic, which is not applicable for WSNs. Recently, probabilistic analysis of delay has been performed for broadcast networks, considering several medium access control (MAC) protocols. While the channel contention has been adequately modeled for delay analysis in these studies, additional delay due to multi-hop communication, queuing delay, and wireless channel errors have not been captured. Capturing these crosslayer effects is imperative to completely characterize the delay distribution in WSNs. Our goal is to provide a comprehensive analytical model for distribution of end-to-end delay in WSNs. Accordingly; the contributions of this paper are as follows: First, we develop a comprehensive and accurate cross-layer analysis framework to characterize the end-to-end delay distribution in WSNs. Second, the effects of heterogeneity in WSNs on latency is captured in terms of channel quality, transmit power, queue length, and communication protocols. Third, the developed framework highlights the relationships between network parameters and the delay distribution in multi-hop WSNs. Using this framework, real-time scheduling, deployment, admission control, and communication solutions can be developed to provide probabilistic QoS guarantees. To the best of our knowledge, this is the first work that provides a probabilistic cross-layer analysis of end-to-end delay in WSNs.

II. RELATED WORKS

The problem of probabilistic QoS guarantees is not trivial and has attracted a large amount of research in recent years. The concept of Network Calculus has been extended to support probabilistic delay bounds. The network calculus and its probabilistic extensions are based on the min-plus algebra to provide traffic curves and service curves, which are deterministic (or statistic) bounds of traffic rate and service time, respectively. In these studies, the worst case performance bounds are analyzed. However, determining worst case bounds has limited applicability in WSNs for three reasons: First, because of the randomness in wireless communication and the low power nature of the communication links, worst case bounds do not exist in most practical scenarios. Second, the large variance in the end-to-end delay in WSNs results in loose bounds that cannot accurately characterize the delay distribution. Finally, most applications tolerate packet loss for a lower delay of higher priority packets since the efficiency of the system is improved. These motivate the need for probabilistic delay analysis rather than worst case bounds. Moreover, work on real-time queuing theory combines real-time theory and queuing theory to provide stochastic models for unreliable networks. However, these models consider heavy traffic rate (usually saturation mode), which is not applicable for WSNs. Our approach in this paper is similar to real-time queuing theory in that we use a stochastic queuing model for the analysis. In contrast, we do not focus on the real-time scheduling problem, which has been discussed intensively in the literature. Rather, we aim to provide an analytical tool to help develop real-time scheduling and communication solutions. Recently, a large amount of studies have analyzed the delay distribution of MAC protocols for wireless networks and WSNs, in particular. The access delay of several MAC protocols has been investigated including IEEE

802.11b DCF protocol in IEEE 802.15.4 protocol and TDMA protocols However, in these studies, a broadcast network is considered, where each node can hear the transmission of each other. Moreover, saturated traffic is considered. Consequently, the multi-hop communication effects due to hidden node problems and the low traffic rate of WSNs cannot be captured. The distribution of link layer retransmissions are modeled In While the distribution of the number of retransmissions is obtained, the transmission time is regarded the same for each attempt. Hence, the resulting delay distribution model does not consider the uncertainty due to random bakeoffs of CSMA/CA protocols. In the end-to-end delay distribution in a linear network is derived for homogeneous networks. However, this model assumes infinite queue lengths at each node, which may not be practical considering the resource constraints of sensor nodes. Finally empirical measurements and estimations are used to route packets so that a probabilistic guarantee of delay is provided. These solutions exploit on-the fly measurements but do not provide analytical results. It can be observed that accurately characterizing end-to-end delay in WSNs is still an open problem. In the following, we provide a cross-layer analysis framework toward this goal.

III. PROPOSED SYSTEM

A. ODMRP

ODMRP assumes that nodes share a single wireless channel organized into time frames consisting of a fixed number of time slots. The objective in STORM is to orchestrate the scheduling, routing, and traffic management functions of a multihop wireless network in a way that sources and destinations of flows perceive the network as a virtual link dedicated to the dissemination of those flows. Accessing the time slots of each frame is based on a combination of distributed elections of available time slots and reservations of time slots. For those time slots that have not been reserved, nodes use a distributed election algorithm based on hashing functions of node identifiers. A virtual link is created to support an individual real-time data flow and is implemented by a set of nodes located at directed meshes connecting sources to destinations. . To provide the abstraction of a virtual link, the routing algorithm also computes an endto- end channel access schedule for each data flow. The schedules generated by ODMRP are such that delay guarantees can be enforced on a per-hop and end-to-end basis. The end-to-end schedules are instantiated by the reservation protocol when the first data packet traverses the flow's routing mesh. The routing meshes established by STORM provide a fast and efficient way of repairing routes, because they contain extra paths that can be used in case of link breaks. This reduces the impact of node mobility on the quality of service perceived by real-time flows. In addition, the routing algorithm establishes enclaves, which restrict the dissemination of control information to those nodes that are likely to participate as forwarders of a given data flow, rather than the entire network. ODMRP uses reservations and a priority-based queuing system to implement and preserve the per-flow channel access schedules. Nodes reserve time slots on behalf of real-time data flows according to their end-to-end schedules and use a priority-based queuing system to select the packets that are transmitted on each slot. The queuing system is composed of queues for signaling traffic, elastic (non realtime) traffic and real-time traffic. Areal-time queue is created for every new real-time flow traversing a node, and it is associated with the time slots reserved for the flow. During the time slot reserved for a given flow, its associated queue is given a higher priority than those assigned to other data Queues. This way, ODMRP establishes a dedicated queuing network for each real-time flow to avoid interference among multiple real-time flows traversing the same nodes.ODMRP uses reservations and a priority-based queuing system to implement and preserve the per-flow channel access schedules. Nodes reserve time slots on behalf of real-time data flows according to their end-to-end schedules and use a priority-based queuing system to select the packets that are transmitted on each slot. The queuing system is composed of queues for signaling traffic, elastic (non realtime) traffic and real-time traffic.Areal-time queue is created for every new real-time flow traversing a node, and it is associated with the time slots reserved for the flow. During the time slot reserved for a given flow, its associated queue is given a higher priority than those assigned to other data Queues. This way, ODMRP establishes a dedicated queuing network for each real-time flow to avoid interference among multiple real-time flows traversing the same nodes.

B.Channel Design And Traffic Management

Nodes share the same frequency band, and we assume that clock synchronization among the nodes in the network is achieved through a multihop time synchronization scheme such as the one implemented in Soft-TDMAC which is a TDMA-based MAC protocol that runs over commodity 802.11 hardware. Nodes access the common channel assuming that it is organized using a time-division multiple access structure, which we call frame and is illustrated in Fig. 1 When a node is allowed to transmit over a time slot, it fits as many packets as possible in it. Packets are selected from the local transmission queues, which are FIFO and are served using a priority-based algorithm. Reservation packets have the highest priority (pRsv), because quick consensus is needed on which nodes should have access to which time slots. The next priority is given to network-layer signaling packets (pctr), and data packets waiting in data queues have the lowest priority. Data queues can be either elastic or real-time, and real-time queues are assigned higher priority (pRT) than the priority given to elastic queues (pelastic), given that jitter and latencies are not as important for the latter.

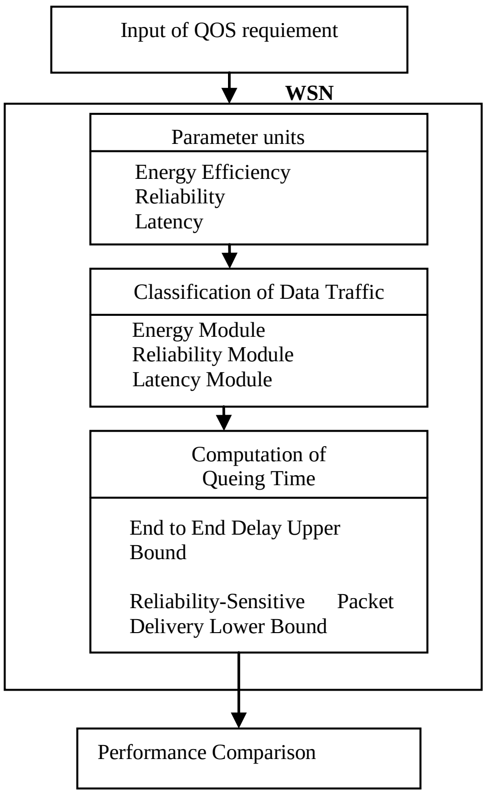

Figure 1. Frame work

C.Neighbor Management Protocol

Routing, reservations, and transmission scheduling in STORM use distributed algorithms that require each node to know the nodes within its two-hop neighborhood. The neighborhood of a node consists of those nodes whose transmissions the node can decode, which we call one-hop neighbors, and the one-hop neighbors of those nodes are called two-hop neighbors. To gather two-hop neighborhood information, each node transmits hello messages periodically every hello period seconds, and each such message contains a list of tuples for the node itself and for each of its one-hop neighbors. Each tuple is composed of a node identifier, a list of the identifiers of the time slots reserved by the node, and the length of the list of reserved slots. Each node stores the last hello message received from each one-hop neighbor (or simply neighbor) in its neighbor list. A neighbor is deleted from the neighbor list if no hello message is received from that neighbor in three consecutive hello periods.

D.Transmission Scheduling

The channel access algorithm consists of three simple ways to determine which node should transmit in a time slot. When a node becomes part of a persistent real-time data flow, i.e., when it starts transmitting real-time data packets for a source-destination pair, it uses the reservation protocol to reserve future slots to be used on behalf of that particular real-time flow access schedules of the relays of the flow are flow ordered. The relays of a flow are flow ordered if every single one of them can access the channel in a time-ordered sequence of slots.

IV. RESULTS AND DISCUSSIONS

A.Simulation results

The use of packet delivery ratio, generalized group delivery ratio, end-to-end delay, and total overhead as our performance metrics. To measure total overhead, thus count all the packets generated by each protocol stack, which for the case of STORM includes data packets, MRs, MAs, hellos, and reservation packets. The generalized group delivery ratio is a multicast-specific metric in which a data packet is considered as delivered, if and only if it is received by at least a given proportion of the multicast group members. This metric emphasizes the importance of group delivery by not considering packets that are received by a small subset of the group members.This paper sets a threshold of 80 percent. The total overhead is computed as the average total number of packets transmitted by each node. We employ random waypoint (RW) and a combination of random waypoint and group mobility models as our mobility models. In our combined scenarios, the members of a given multicast group move following the group mobility model, whereas nodes that do not belong to a multicast group move according to the RW mobility model.

B.Comparison metrics

The present simulation results comparing ODMRP with ODMRP , AODV and OLSR for the case of traffic. In our experiments, ODMRP, AODV, selected these protocols because they have become de facto baselines for performance comparisons of multicast, unicast, and channel access protocols. Even though they were not designed for real-time traffic, they are a good reference that allows us to highlight the performance gains of our approach. Introducing ODMRP, a cross-layer protocol framework for wireless ad hoc networks that integrates interest-driven routing with priority-based queuing for traffic management, end-to-end bandwidth reservations controlled by the routing, and distributed transmission scheduling. All these components work together to provide end-to-end delay and bandwidth guarantees to real-time unicast and multicast data flows in multihop wireless networks even when nodes move.

V. Conclusion

Proving that the routing meshes established with ODMRP are loop-free at any time and that the end-to-end reservations established along routing meshes provide bounded delays to real-time data packets. Our simulation results confirm our correctness results showing that ODMPR is very scalable and robust for both unicast and multicast traffic. The results also show that STORM's main limitation is the need for time-slotted channel access requiring clock synchronization; however, viable approaches exist to attain this.

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