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Evaluation of available bandwidth as a routing metric for delay-sensitive IEEE 802.15.4-based ad-hoc networks☆

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ABSTRACT

In this paper, we evaluate available bandwidth as a routing metric for IEEE 802.15.4-based ad-hoc networks. The available bandwidth on a data forwarding path is an approximation of the forwarding path's residual data relaying capacity. High available bandwidth on a data forwarding path implies low data traffic load on the path, therefore data flows may experience low delay and high packet delivery ratio (PDR). Our aim is to evaluate available bandwidth as a routing metric. We present different available-bandwidth-based routing protocols for IEEE 802.15.40-based networks, namely: end-to-end available-bandwidth-based routing protocol (ABR), available bandwidth and contention-aware routing protocol (ABCR), and shortest hop-count and available-bandwidth-based opportunistic routing protocol (ABOR). Moreover, we also present variants of ABR and ABCR capable of distributing a flow's data packets on multiple paths by maintaining the top *K* downstream nodes (the downstream nodes that advertised best data forwarding paths towards a sink node) corresponding to each sink node in a routing table. We focus on both single-sink and multi-sink networks. We performed extensive simulations, and the simulation results demonstrate that the available bandwidth routing metric shows better results when combined with a routing metric that helps to limit a data forwarding path's length, i.e., shortest hop-count or intra-flow contention count. For multi-path data forwarding towards the same sink node, and at high traffic volumes, the available bandwidth metric demonstrates best performance when combined with the shortest hop-count routing metric.

1. Introduction

The IEEE 802.15.4 standard is being actively used in wireless networks, e.g., industrial control applications [1]. In this research, our vision of IEEE 802.15.4-based ad-hoc network is depicted in Fig. 1. The example network shown is used to monitor traffic on a network of roads. Such a network can generate delay-sensitive data flows, e.g., vehicle tracking and traffic load on different roads. Afterwards, the data is forwarded to one of the sink nodes, and if required the sink node forwards data to the network controller, which we assume has a high speed connection to the sink.

A routing protocol discovers a data forwarding path from a source node to a destination node, and the state of links on the discovered path impacts the delay and packet delivery ratio (PDR) requirements of a data flow. For example, if a routing protocol discovers a path with congested links, it is highly likely that a flow may experience high end-to-end delay and low PDR. In order to discover a path, the routing

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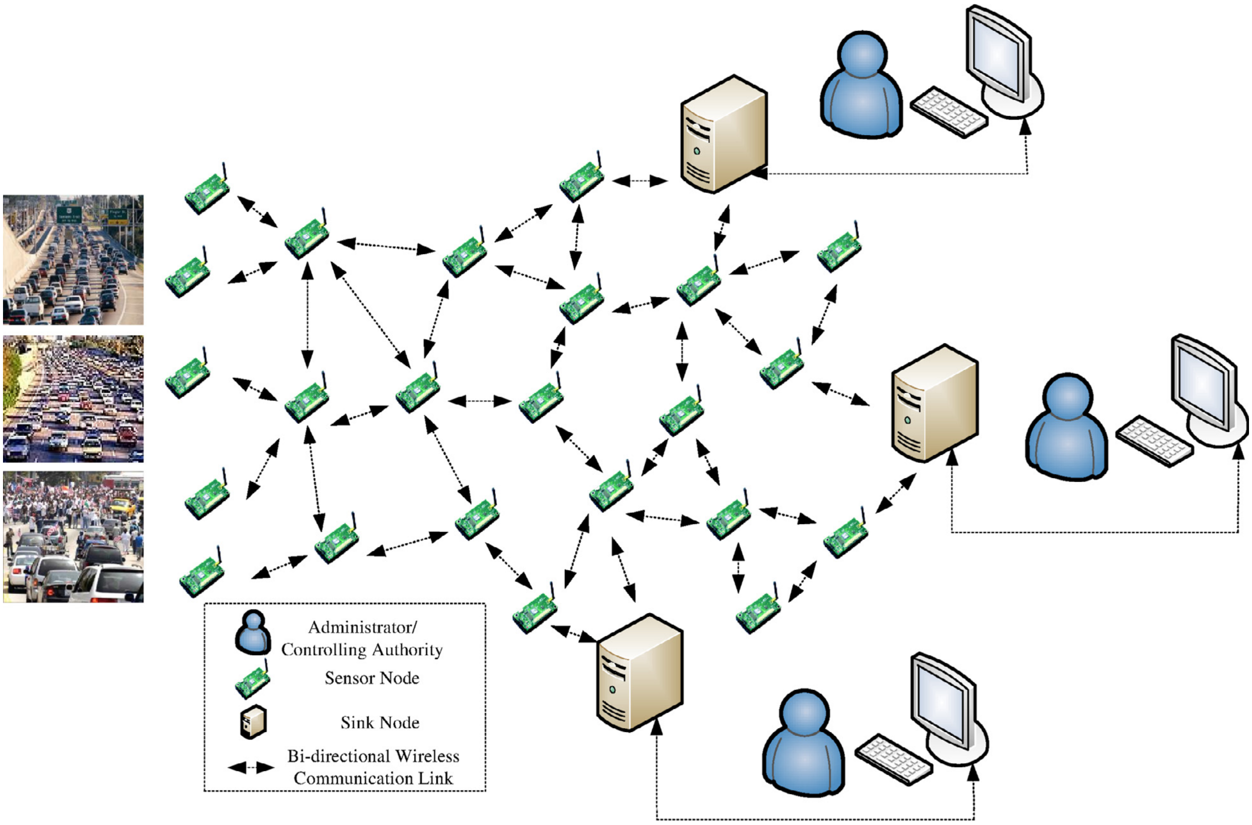

Fig. 1. An example of an IEEE 802.15.4-based ad-hoc network.

protocol uses a routing metric, e.g., the shortest hop-count routing metric. The choice of a routing metric can impact the quality of the discovered paths. For example, paths generated based on the shortest hop-count metric may include links with excessive data traffic, and that the flow may experience high delay and low PDR. The number of paths that a routing protocol discovers and maintains towards a destination node can also impact the performance of a flow. A routing protocol that discovers and maintains multiple best paths, and afterwards distributes a flow's data packets on those multiple paths may demonstrate better performance compared to a routing protocol that forwards the flow's data packets on a single best path.

The bandwidth supported by a communication standard determines the standard's data transmission rate. In IEEE 802.15.4-based networks bandwidth is a shared resource, as nodes within each other's interference range share the bandwidth. Therefore, the data generation rate of a node impacts the amount of bandwidth available to other nodes within the node's interference range. In ad-hoc wireless networks, a carrier sense multiple access collision avoidance (CSMA-CA) MAC layer protocol consumes bandwidth, e.g., a node cannot transmit while it is waiting in a back-off mode due to busy channel and packet losses [2,3]. We focus on the available bandwidth as a routing metric because it is an approximation of the residual data relaying capacity of a wireless channel, and it implicitly takes into account the wireless channel condition. For example, as the number of packet losses increases the back-off duration also increases, hence the available bandwidth decreases [2,3]. Moreover, it can capture dynamic changes in wireless channel conditions and data traffic load inside a network. Therefore, the available-bandwidth-based routing metric can help a routing protocol to discover data forwarding paths that may help to improve the performance of data flows.

In this paper, we present an evaluation of available bandwidth as a routing metric in single-sink and multi-sink IEEE 802.15.4-based ad-hoc networks. The following are our main contributions:

1. Different ways of utilization the available bandwidth as a routing metric, e.g., considering the end-to-end available bandwidth, combining the available bandwidth with other routing metrics, i.e., shortest hop-count and intra-flow contention count.
2. Using the presented routing metrics for discovering and maintaining single and multiple data forwarding paths in single-sink and multi-sink networks.
3. Discovering the limits of the available bandwidth as a routing metric, i.e., an available-bandwidth-based routing metric demonstrates better results when combined with other routing metrics, e.g., shortest hop-count and intra-flow contention count. For multi-path data forwarding, and at high traffic volumes an available-bandwidth-based routing metric demonstrates best results when combined with shortest hop-count routing metric.