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On the interest of opportunistic anycast scheduling for wireless low power lossy networks

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ABSTRACT

Low-Power and Lossy Networks (LLNs) aim at integrating smart objects into the Internet of Things. IEEE 802.15.4 -TSCH is currently a promising standard for the link layer: it schedules the transmissions and implements slow channel hopping to improve the reliability while the routing layer focuses on constructing distributed routes for a small collection of destinations (i.e. convergecast). We propose an efficient scheduling policy to exploit an opportunistic feature of the MAC layer: a single transmission is received by a collection of next hops which decides opportunistically which one will forward the packet. We consider the problem of the optimal scheduling policy for reliability and energy efficiency with considering such opportunistic forwarding at the MAC and routing layers. The simulation results demonstrate the effectiveness of the proposed policy: by effectively selecting the set of parents (i.e. next hops) and carefully considering the channel quality, the energy consumption per packet is reduced. Besides, we also improve the reliability: the network can also use unreliable radio links, where only one of the next hops receives the packet to forward. This scheduling policy may be typically implemented in the Path Computation Engine of IEEE 802.15.4 e-TSCH.

1. Introduction

Recent advances in technology made possible the creation of smart objects that can be interconnected to create the new Internet of Things. The IEEE 802.15.4 working group proposed in 2012 an amendment to enable energy efficient networking for the industrial market [1]. Since transmissions are often predictive, the TSCH (TimeSloted Channel Hopping) mode proposes to assign timeslots coupled with a slow channel hopping strategy to improve the reliability. To enable the energy efficiency, TSCH implements an implicit synchronization: any data or control packet may be used by the receiver or the transmitter to compute the clock drifts. This strategy is particularly efficient for periodic and/or predictive transmissions.

In multihop networks, a centralized Path Computation Engine (PCE) may compute the path to use for each flow. Alternatively, a routing protocol such as RPL may distributively construct the routes [2].

For a convergecast traffic, most of the approaches construct a Directed Acyclic Graph rooted at the border routers (i.e. gateways to the Internet). Then, each node has a set of parents, which constitute the next hops toward the border routers. However, RPL currently selects only one parent to forward all the traffic – the other ones just serve as a backup purpose. We propose here to modify the MAC forwarding strategy to enable opportunistic forwarding, exploiting all the parents to improve the reliability. Indeed, loosing packets may be prejudicial for many applications since packets may not be redundant (e.g. water metering, smart parking, etc.)

Scheduling the transmissions after selecting the routes to use has recently attracted much attention. In particular, the 6TiSCH working group [3] aims at defining the mechanisms to enable RPL to work on top of IEEE 802.15.4 TSCH. 6TiSCH defines a bootstrapping procedure with a minimal configuration so that a central controller (the Path Computation Engine – PCE) is then able to compute an efficient schedule. However, 6TiSCH currently focuses on unicast transmissions, with the concept of *tracks*. We aim at going further in this direction, with an opportunistic version of IEEE 802.15.4 -TSCH, exploiting several parents in parallel to increase the reliability while decreasing the energy consumption. Typically, our solution may be implemented in 6TiSCH with a centralized controller (PCE).

Proposing an efficient schedule also requires determining the optimal transmission power. Indeed, using the maximum power may improve the reliability but may also increase the energy

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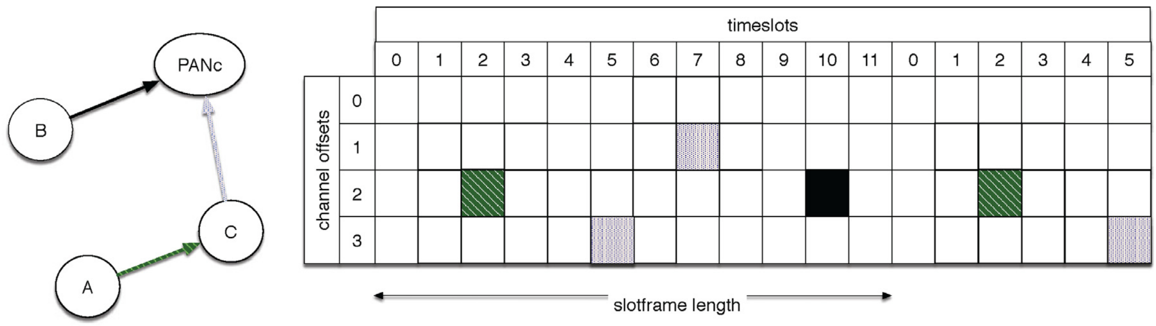

Fig. 1. Structure of the IEEE 802.15.4 -TSCH superframe.

consumption [4]. Besides, the channel quality varies with time due to fading. Thus, we can achieve significant energy conservation by scheduling transmission during the time that the channel is in good quality [5].

In this paper, we consider the problem of scheduling in multi-hop convergecast networks to improve both the end-to-end reliability and the global energy consumption. In particular, we use the multiple parent opportunistic scheduling at the MAC layer to cope with individually faulty links. The contributions of this paper are two-fold:

1. We provide a dynamic and stochastic formulation of the problem by using dynamic programing. This policy can maximize a combination of reliability and energy consumption.(Section 4) We propose an approximate algorithm, which considers the problem in close form function rather than discrete value, to reduce the computational complexity (Section 5).
2. We thoroughly evaluate the performance of this algorithm by simulations. Our scheme results in a lower energy consumption and a better end-to-end reliability compared to the myopic scheduling strategy and the single-parent scheduling strategy (Section 6).

2. Related work

2.1. IEEE 802.15.4 e-TSCH

IEEE 802.15.4 -2006 [6] was introduced at first in Personal Area Networks (PANs). While it enabled through Zigbee, the adoption of IEEE 802.15.4 for the Internet of Things (IoT), it limits in multihop topologies [7], and leads to many collisions [8].

In 2012, the working group proposed the IEEE 802.15.4 -TSCH amendment [1] to set-up an industrial wireless network. TSCH adopts a FTDMA strategy such as Wireless HART [9] to mitigate interference and multipath fading. Besides, TSCH is deterministic to provide predictable performance.

In IEEE 802.15.4 -TSCH, a schedule is established so that at the beginning of each timeslot, each node knows if it has to stay awake to receive or transmit a frame. In the IEEE 802.15.4 -TSCH jargon, a *cell* represents a transmission opportunity, denoted by a timeslot and a channel offset. We denote in this paper by cell the pair $<$ *timeslot,channelOffset* $>$.

The superframe structure is depicted in Fig. 1. A slotframe contains a certain number of timeslots and repeats over time. A slot may be either dedicated to one transmitter or shared among a group of interfering nodes. In Fig. 1, the radio link $C \rightarrow PAN_c$ reserved two cells (timeslots 5 and 7) for its transmissions.

TSCH may use a centralized scheduling, with a Path Computation Engine (PCE). This PCE is the central entity in charge of computing the paths used by each flow, and the cells used by each radio link. In that case, the 6TiSCH architecture is an extension of the Deterministic Networking Architecture [10], adopting a Software-Defined Networking approach.

The schedule may also be decentralized, decided one-by-hop with the 6top protocol to negotiate a group of cells [11]. Because each pair of nodes selects autonomously the cell to use, interference may arise. Some mechanisms are required to monitor and adapt the local schedule [10].

Interference may arise in the following cases:

Internal interference occurs if the same cell is allocated to a pair of interfering transmitters. Since no medium access is implemented, the collision will occur in *every* cell.
We assume here the interfering topology is a priori known, and that our scheduling algorithm prevents to allocate the same cell to two different interfering transmitters. We neglect consequently this internal interference.

External interference may come from other wireless technologies (Bluetooth, Wifi, etc.) since we use the ISM band [12,13]. However, channel hopping is particularly efficient to alleviate this kind of external interference, reducing the number of retransmissions [14].
We consider here that external interference impacts negatively the Packet Error Rate (PER): more cells have to be allocated when external interference is present. Besides, we focus on long-term performance, i.e. the external interference is sufficiently stable to be estimated via the PER, and thus considered in the scheduling process. We investigate the impact of the external interference in the simulation.

2.2. Routing

RPL [2] was designed for low power lossy networks (LLN), mainly for convergecast traffic, i.e. all the packets are collected by a border router.

The standard constructs a Destination Oriented Directed Acyclic Graph (DODAG): each node maintains a collection of parents, and the routing structure does not form any cycle. In the forwarding plan, a node chooses to forward all its packets to its preferred parent, other parents constitute backup solutions if the preferred one fails.

To construct a DODAG, each node computes a *rank*, denoting its *virtual distance* from the border router. Then, a node selects any node with a lower rank as parent (Fig. 2). Lampin et al. [15] proposed an opportunistic forwarding version of RPL to exploit also long radio links with a poor reliability. The parent with the higher priority acknowledges first the packet. They use an opportunistic MAC layer, where a single transmission is sufficient to forward the packet to all the parents. Opportunistically, the parent with the highest priority and which received the packet acknowledges