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A Survey on Techniques to Identify Active Devices and their Channels in an IoT Networks

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Abstract – Before nodes may send data in an IoT (Internet of Things) network, they must first access the network's resources. The node shouldn't become stalled when trying to access resources if the data being transferred needs real-time assurances. For timely data communication, quick and effective access to the network resources is preferred. In order to do this, we investigated the IEEE 802.15.4 and IEEE 802.15.4e-TSCH standards and put forth energy-saving algorithms to guarantee that the nodes may access the resources as soon as possible. For IEEE 802.15.4 networks, we have put forth the "Device Registration" approach, which intends to improve access to the Guaranteed Time Slots (GTSs) included in the superframe. The settings of the current MAC framework can be slightly altered to implement the method. For IEEE 802.15.4e-TSCH networks, we've also suggested a "Sparse Beacon Advertisement," a beacon scheduling technique that tries to shorten the wait time for a new node before it enters the network, even when there aren't many beacons being advertised. Both of these algorithms have undergone in-depth testing on a testbed utilising simulations and experimentation. Our findings demonstrate that nodes are twice as effective as they were before in gaining access to GTS resources in an IEEE 802.15.4 network when using the suggested approach. Similar to this, in an IEEE 802.15.4e-TSCH network, sparse beacon advertisement cuts joining times by at least 60%.

Keywords – Guaranteed Time Slots, Internet of Things

I. INTRODUCTION

Internet of Things (IoT) consists of a large number of interconnected sensor and actuator nodes that communicate with each other to facilitate intelligent and autonomous applications such as safety, security, environment monitoring, asset management, healthcare, etc. The application of energy harvesting technologies due to advancements in low power process technologies [1] has further accelerated untethered operations of these nodes. For example, state-of-art technologies can achieve an active current of 20μA/MHz and a deep standby current of 150 nA [2]. Integrating these low power operational capabilities with low power communication technologies like Bluetooth Low Energy (BLE) [3], Z-Wave [4], IEEE 802.15.4 [5], and IEEE 802.15.4e [6] hold the promise of extended lifetimes for mission-critical condition monitoring applications. These applications generate sporadic data, which is mostly event triggered and must be communicated across the network with near-real-time guarantees. In these applications, the nodes usually stay in a low power mode and communicate only when events are detected. We also observe that the epicenter of such events is restricted to a subset of "active" nodes. For example, in an intrusion detection system, only the nodes at violated entry points will be triggered while detecting an intrusion. In contrast, the rest of the nodes can still maintain their regular duty cycle.

Any network communication comprises of a handshake over the control channel and an eventual data transmission on the data channel. There are many low power MAC schemes well suited for data channels. In contrast, the energy consumption of control channels is often ignored with the assumption that it is mostly setup related and will be incurred "only once". For instance, in the beacon enabled mode of IEEE 802.15.4 technology, nodes must contend to send out their access requests for the Guaranteed Time Slots (GTSs) in the Contention Access Period. This method not only suffers from nondeterministic delays to obtain resources, but it also exhausts a significant amount of energy. Even though the standard was amended in 2015 and two MAC behaviors, *viz.*, Deterministic and Synchronous Multichannel Extension (DSME) and Time Slotted Channel Hopping (TSCH), were incorporated in the IEEE 802.15.4e-2015 revision [6] to support real time guarantees, robustness, reliability and flexibility in data transmission in the emerging Industrial IoT (IIoT), assumptions regarding energy consumption in control channel remain consistently in place. The IEEE 802.15.4 technology has a massive market footprint. Currently, half a billion chipsets are available, and this number is likely to touch 4.5 billion by the year 2023 [7]. Additionally, manufacturers have also released combo chipsets. For instance, nRF52840 from Nordic Semiconductor is an advanced Bluetooth 5, Thread, and Zigbee multiprotocol SoC [8]. Moreover, the IEEE 802.15.4e-2015 amendments are limited to the MAC sublayer of the IEEE 802.15.4 while the physical layer of the standard is kept intact. Therefore, any node that supports the IEEE 802.15.4 radio can be upgraded to support TSCH based MAC as well. It is, therefore, important to study the energy consumption of communication protocols in a holistic manner by including control channels to complete the picture. In this work, we study the IEEE 802.15.4 and IEEE 802.15.4e-TSCH protocols and show how delays in control handshakes can be avoided to ensure ultra-fast access to resources and prompt data transmissions.

Although the beacon enabled mode of networking in IEEE 802.15.4 is a mature technology, it cannot support time-critical sporadic data transmission in its current form. Fig. 3 shows that the performance of slotted CSMA/CA, *i.e.*, the probability with which nodes can access the GTSs, is low due to two major shortcomings:

1. Channel assessments and backoffs are required to perform the control handshake for accessing the GTS resources, due to which the node may not be able to support real-time guarantees.

2. GTS resources, once acquired, get reserved, which might not be suitable when working with a network where the number of active nodes is dynamic. Reservation might lead to starvation of another node and poor utilization of these resources.

To this end, we propose a "Device Registration" algorithm, which acts as a precursor to the rich literature around the efficient GTS resource usage schemes. Our algorithm provides nodes with efficient access to GTS resources. To deal with the first concern, we restrict the transmission of request packets in the Contention Access Period (CAP) without any channel assessments and backoffs. Also, CAP is divided into "microslots" so that more number of request packets can be transmitted. In addition, we propose eliminating the reservation of GTS resources so that they can be appropriately utilized by the active nodes to mitigate the second concern. The proposed algorithm benefits networks that are powered by battery and harvested energy alike.

TSCH can support large networks that need strict real time guarantees [9]. It combines frequency hopping capabilities with Time Division Multiple Access (TDMA) and relies on Enhanced Beacons (EBs) for the formation of the network. These are broadcasted at regular intervals in the network on different channels according to the channel hopping rules to synchronize and advertise the network. A new node that wishes to join the network gets associated with the network once it receives one of these beacons. However, such a node is unaware of the channel hopping rules and might spend a large amount of time and energy waiting for the reception of an EB before it can sync with the network and start communicating. This can be seen from the entries corresponding to the Minimal Configuration in Fig. 6 and Table 2. This wait time is termed association time or the joining time. It depends upon the number of EBs being transmitted and their frequency. On the one hand, transmitting fewer EBs or transmitting them less often can lead to long joining times. However, transmitting large number of EBs or frequent EB transmission might lead to EB collisions which again will lead to long joining times. To address this, we have devised a beacon scheduling algorithm called the "Sparse Beacon Advertisement" that reduces the joining times in scenarios when there are only a few beacons being advertised in the network. Since we are able to achieve low joining times with few beacons, we are now not required to increase the number and frequency of beacon transmission. Hence, we can altogether avoid scenarios where the joining process is delayed due to beacon collisions. Reduced joining times also result in significant energy savings for the node trying to join the network.

The following are the major contributions of the paper:

1. Proposed a novel "Device Registration" algorithm for improving the real-time support of IEEE 802.15.4 and demonstrated that the proposed algorithm can be implemented with minor modifications to the parameters without violating the existing MAC framework of the beacon enabled mode of IEEE 802.15.4.

2. Evaluated the proposed "Device Registration" algorithm thoroughly using a testbed of 7 nodes, all of which support IEEE 802.15.4. The nodes form a star topology around the PAN coordinator. The transmission power is set at 0 dBm, and Channel 26 has been used for communication. Comprehensive MATLAB simulations were also performed to study the scalability of the proposed algorithm.

3. Proposed a "Sparse Beacon Advertisement" for scheduling Enhanced Beacons (EB) in an IEEE 802.15.4e-TSCH network to facilitate quick and efficient association of nodes with the network even when there are few EBs being broadcasted in the network.

4. Evaluated and compared the performance of the proposed "Sparse Beacon Advertisement" algorithm with different beacon scheduling algorithms with the help of extensive MATLAB simulations. A TSCH network was also implemented with the help of nodes that support IEEE 802.15.4. The network emulates the process of beacon advertisements in TSCH by combining beacon enabled mode of IEEE 802.15.4 with channel hopping capabilities. The network does not support data transmissions and is constructed solely to validate the reduction in joining times as observed during simulations and to calculate the reduction in the joining node's energy expenditure.

The rest of the paper has been organized as follows: Section 2 gives a small overview of the IEEE 802.15.4 and IEEE 802.15.4e-TSCH standards. Section 3 discusses the research works that have been conducted with respect to both these standards. Section 4 gives the details about the proposed "Device Registration" algorithm for the IEEE 802.15.4 networks along with the details of its implementation, evaluation, and a discussion on the obtained results. Details for "Sparse Beacon Advertisement" are provided in Section 5 along with the details of its implementation, evaluation, and insights from the results.

II. RELATED WORKS

Previous techniques for high-dimensional channel estimation and significant connective device problems are described in this literature section. The spatial and temporal prior knowledge was exploited[11]. The techniques for channel estimates (CS) in the Doppler domains, angular, frequent, and time, have been proposed to use the sparsity of the channel structures[12]–[14] to solve the high-dimensional channel estimating issue.

To address the computation issue it isalso critical to develop efficient algorithms Due to the large-scale nature of IoT communications.

To enhance the channel estimationperformancein thedevice activity patternit is critical to further exploit the sparsity in IoT networks with a limited channel coherencetime [3], [10], to reduce the training overhead.

We focus on thenonorthogonal multiuser access (NOMA) scheme To support a massive number of devices, [9], which can simultaneously respondto multiple devices via nonorthogonalresource allocation.in [19] it is studied The information theoretical capacity was studied.for supporting massive connectivityIn paper [9] author investigated the challengesof NOMA and its opportunities. to estimate the channels detect the active devices,aCS-based formulation [10], [20]yielded by The sparsity activity pattern. Furthermore, by deploying more radio access points in IoTnetworks [18] the network densification [17]supports massive deviceconnectivity, enables low-latency mobile applications,and improves network capacity.

The sporadic device activity detection problem is investigated recently.a connectionbetween the BS shall and an active device be established,In the random access scheme if theorthogonal signature sequence randomly selected by the activedevice is not used by other devices. in [15] researcher has investigated the randomaccess scheme In the context of cellular networks. In paper [16] discussed to dealwith the massive numberof devices overhead incurred. Collision between largecount of devices occurred by this scheme, however.

This proposal can be solved by proposing structural sparsity settlement methods that can overcome and remove overheads for statistical data from the channel and obtain large-scale coefficients without prior knowledge of the CSIthe JADE problem distribution. We provide detailed characterization for the standardized group sparsityestimation problem for transitional behaviors to determine the optimal duration of the signature sequence. Reference[23] on the basis of the minimal isometry property [28] Presented the boundaries to the nonorthogonal multi-access device multiuser identification mistake. Usually for clinicians, the order-specific figures are not reliable. Ref[27] suggested the alternative multiplier path method (ADMM) algorithm without output analysis. Subsequent phase transition was examined in [30] and [31] using the conic integralgeometry theory, which defined conditions for the success and failed signal recovery of a regularisedlinear inverse problem. The phase transition was then studied. The position and width of the transformation are in particular basically influenced by the statistical dimension of the convex-regularizing descent cone. Such results are also only applicable within the context. Also, the appropriate requirements for signal recovery guarantees can only be given with this method.

In research [26], the channel reservation technology for hand-off was introduced in order to reduce the risk of falling and blocking calls, and the key idea was the identification of the active devices in the IoT network. As per perfectCSI, a multiuser detection criterion was established for sparsity maximum a posteriori in CDMA [20]. [23]. Nonetheless, in order to will overhead signals, our solution does not require any previous CSI delivery information. In [10], [24] and [25] a common method has been developed to estimate channels and detect user behavior through a Messages Process Algorithm (MPA) to improve the Bayesian AMP algorithms through robust performance analysis using statistical channel information and large-scale coefficients. The problem of multiuser identification by channel-prior information was considered and Du, etc. [23]. In particular, CSI refers to distribution information in similar claims of "previous experience of CSI." The CSI referred in [21] to the canal spreading coefficient that describes how a signal propagates between transmitters and receivers. In [21] the CSI has been proposed to forecasts the conditions of the channel for unmanned aircraft communication.

The tradeoff method is often guidance to choose the signature sequence length to preserve approximate precision. It results in a balance between measurement costs and accuracy of predictions, as the increase of the smoothing parameter typically reduces the accuracy. In this study, the smoothing approach is used by increasing the convergence rate to solve the problem of high-dimensional category estimates with a fixed time budget. Giryes et al. [41] demonstrated that by adjusting original iterations, higher convergence rates can be achieved to retain accurate estimates without substantially raising the computational costs of the individual iterations..

The approach is also ideal for solving an overdetermined system instead of the underdetermined linear system. However, this approach also means the solution to the problems of an overdetermined system. Therefore, in this study we based on the first order process. In addition, the cost of each iteration can be cut down by drawing approaches[38],[39], to reduce the computational complexity. In comparison, methods of initial use, for instance gradient, proximal[33], ADMM [34],[35], quick ADMM [36] are especially useful when dealing with major problems. When solving JADE with fixed time budgets, the large number of devices in IoT networks poses specific computational challenges. Unfortunately, in large scale optimization issues because of the low scalability, the second-order method of the internal dotte process is not valid.

After having discussed some background about the protocols, we now discuss recent works in the field of IEEE 802.15.4 and IEEE 802.15.4e-TSCH.

Adapting IEEE 802.15.4 for improved device registration probability

To implement the proposed "Device Registration" algorithm for IEEE 802.15.4 networks, we have considered a network that consists of energy-constrained nodes, out of which n nodes are active at any given time, and a grid-powered base station (Fig. 1(a)). The nodes and the base station are arranged in a star topology. To support real-time data, the network implements the beacon-enabled mode of IEEE 802.15.4. Data transmission is prohibited during CAP and allowed only using the GTSs. To gain

Sparse Beacon Advertisements for faster node associations in IEEE 802.15.4e-TSCH networks

From the previous sections, we have gathered that for large networks that require real-time guarantees, employing the IEEE 802.15.4e-TSCH standard is beneficial. However, as explained in Introduction 1, TSCH is a relatively new MAC standard and suffers from long joining times before a new node can join the network, especially if there are very few beacon advertisements. Hence, in this paper, we have attempted to tackle beacon scheduling in a network with a limited number of beacons.

III. CONCLUSIONS AND FUTURE WORK

In this work, we have studied networks where data transmissions have associated deadlines. We have proposed methods that facilitates quick access to the network resources so that data transmission deadlines are not compromised. We have worked with IEEE 802.15.4 and IEEE 802.15.4e-TSCH networks. We have proposed a "Device Registration" algorithm using which the existing deployments of IEEE 802.15.4 networks can be made suitable for handling time-sensitive sporadic data. The algorithm implements

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