A novel scheme for congestion notification in IoT low power networks

Moussa Aboubakar
Sorbonne Universités, Université de Technologie de Compiègne, CNRS, HEUDIASYC UMR 7253, CS 60319
Compiègne Cedex 60203, France
moussa.aboubakar@hds.utc.fr

Pierre Roux
Université Paris-Saclay, CEA, List,
F-91120, Palaiseau, France
pierre.roux@cea.fr

Mounir Kellil
Université Paris-Saclay, CEA, List,
F-91120, Palaiseau, France
mounir.kellil@cea.fr

Abdelmadjid Bouabdallah
Sorbonne Universités, Université de Technologie de Compiègne, CNRS, HEUDIASYC UMR 7253, CS 60319
Compiègne Cedex 60203, France
bouabdal@utc.fr

***Abstract*—In this paper, we present a novel scheme for transmission of congestion state of IoT (Internet of things) low power nodes managed by a central entity. The proposed scheme enables an efficient aggregation of congestion state of nodes, in a given routing path, into a block called Congestion Information Block (CIB), which contains binary values representing the congestion state of nodes. Simulation results show that the proposed scheme provides a good performance compared to Explicit Congestion Notification mechanism (ECN) in terms of network throughput, network overhead and offers low divergence (regarding the time of observation) between the network congestion observed by the network manager and the real congestion of nodes.**

***Index Terms*—IoT networks, Congestion Notification, Congestion Information Bock.**

I. Introduction

IoT low power networks are category of Internet of Things networks (IoT networks), which are composed by embedded devices with limited resources (power, memory, processing resources, etc), and typically communicating over wireless links. Today, such networks are used in various applications of our daily life such as smart factory, smart home, smart transportation, smart healthcare, smart agriculture and so forth [1]. However, due to their limited resources, IoT low power networks will face network congestion whenever the traffic load exceeds the available capacity at any point in the network [2]. This congestion problem induces packet loss ratio and hence, the degradation of the wireless channel throughput.

In order to cope with the congestion problem in IoT low power networks, various congestion control mechanisms have been proposed in the literature [3]–[5]. These mechanisms operate in three steps: 1) congestion detection, 2) congestion notification, and 3) congestion mitigation. Congestion detection refers to the process of monitoring IoT low power networks in order to detect both the presence and location of a congestion. This is done by monitoring a number of parameters such as buffer occupancy (queue length), and channel load. Whenever there is a congestion problem or risk in a given network, the congestion notification allows a network node to notify the upstream or downstream nodes so that the appropriate congestion control decision can be taken. In general, the notification of the upstream or downstream nodes is done through Explicit Congestion Notification (ECN) or an Implicit Congestion Notification (ICN). An ECN notification consists in sending congestion information in a specific control packet to the upstream or downstream nodes [6]. An ICN notification consists in sending congestion information by piggybacking the congestion information in a payload of a packet header [5]. After the detection and notification of a congestion problem in the network, the mitigation strategy of the network congestion is done using various techniques such as transmission rate control, load balancing and duty cycle adjustment.

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Congestion notification represents an important step for congestion control in IoT low power networks, since it allows taking the right decision against congestion, according to the congestion state of the network. However, in an event-driven application of IoT low power networks (e.g. forest-fire detection), existing congestion notification schemes like ECN may generate an important network traffic overhead that will increase the risk of network congestion, and thus cause the deterioration of the network performance.

In this paper, we propose a novel congestion notification scheme that enables the transmission of congestion state of IoT low power devices using a Congestion Information Block (CIB) to be sent to a central entity (the network manager). More precisely, the proposed scheme allows an efficient aggregation of congestion state of nodes in a given routing path into the CIB by using binary values. Compared to an ECN scheme, our proposed solution improves the network throughput, reduces the network overhead related to control messages and offers low divergence between the congestion state observed by the network manager and the real congestion state of nodes.

The contribution of this paper is threefold:

1) We propose a novel scheme for congestion notification in IoT low power networks and show how it enables an efficient aggregation of congestion state of nodes in a given routing path.

2) We provide a description of different operations performed by the network manager in order to analyze the CIB.
3) We present an evaluation of our proposed solution to demonstrate its performance compared to Explicit Congestion Notification (ECN); a well known congestion notification scheme.

The rest of the paper is organized as follows: section II presents related works on congestion control in resource-constrained networks with their congestion notification mechanisms; section III describes our solution, which is followed by the presentation of the performance evaluation of our proposal that is given in section IV; and section V concludes this paper.

II. Related work

The intrinsic resource limitation of IoT low power networks has enticed the research community to propose various solutions for congestion control in order to enable a better utilization of available network resources [2], [5], [7].

Sankarasubramaniam et al. [8] proposed a transport solution, called Event-to-Sink Reliable Transport protocol (ESRT) to achieve a reliable event detection in IoT low power networks with minimum energy expenditure. The proposed solution uses a congestion detection mechanism based on local buffer level monitoring in sensor nodes. ESRT includes an explicit congestion notification mechanism to send the congestion state of node to the sink. In the same vein, Wan et al. [9] proposed an energy efficient congestion control scheme for IoT low power networks called CODA (COngestion Detection and Avoidance). The proposed solution uses Queue length and channel load to detect congestion. In CODA, an explicit congestion notification mechanism is used. Similarly, Yukun et al. [10] proposed a centralized congestion control routing protocol based on a multi-metrics (CCRPM) for IoT low power networks. In CCRPM, the congestion notification consists in adding a congestion notification bit into a control message that allows to update the network route.

Collectively, the above solutions use explicit congestion notification mechanism. In event-driven or in large scale resource-constrained networks, this strategy may lead to a waste of network resources. To address this issue, another category of congestion notification solutions has been proposed. This category of solution called implicit congestion notification does not require the creation of a specific packet for congestion notification. Rather, it consists in sending congestion information by piggybacking it in a payload of a data packet header.

Tao and Yu [11] proposed an improvement of CODA called Enhanced Congestion Detection and Avoidance (ECODA), which uses dual buffer thresholds and weighted buffer difference for congestion detection. The congestion notification is done using an implicit congestion notification mechanism. Wang and Liu [12] have proposed an upstream hop-by-hop congestion control (UHCC) protocol based on cross-layer design to mitigate congestion in resource-constrained networks. UHCC uses buffer size and packet delivery rate to detect congestion. After congestion detection, an implicit congestion is used to trigger an update of the traffic rate of child nodes. Singh et al. [13] have proposed a congestion control solution for resource-constrained networks based on the new hybrid multi-objective optimization (PSOGSA) which combines Particle Swarm optimization (PSO) and Gravitational Search Algorithm (GSA). Similarly to [12] and [11], this proposal uses an implicit congestion notification mechanism.

However, congestion notification mechanisms used in the above solutions for congestion control may be inefficient for congestion control in event-driven resource-constrained networks because of possible overhead created by control messages.

Recently, the concept of In-band Network Telemetry (INT) has emerged to enable hop-by-hop collection of network status information through business packets to achieve end-to-end visualization of network services [14]. INT enables the collection of the network status by inserting meta-data into packet by switching nodes. Several frameworks based on INT have been proposed to enable applications such as fault location, congestion control, routing decision and so forth. These frameworks include: Active network telemetry (ANT), In situ operation administration and maintenance (IOAM) and alternate marking-performance measurement (AM-PM). Nevertheless, as mentioned in [14], INT may generate a large amount of telemetry data, which increases the burden of data collection, storage and analysis on server.

In this paper, we propose a novel scheme for congestion notification in resource-constrained networks. The proposed scheme enables an efficient aggregation of congestion state of nodes in a routing path into a Congestion Information Block inserted in a single data packet to be sent to the network manager. This entity is responsible for taking decision of congestion mitigation. Our solution reduces the overhead related to control messages while providing an up to date congestion state of nodes to the network manager.

III. Proposed scheme for congestion state notification

A. Assumptions and problem formulation

We consider an event-driven IoT low power network composed of k nodes scattered over a 2-dimentional area. The set of nodes is represented by $S = \{n_1, n_2, \cdots, n_k\}$. Each node has a unique identifier $i \in \{1, \cdots, k\}$. We assume that all the nodes are homogeneous (in terms of wireless communication technology and computational capabilities) and are topologically static. We also assume that the network is managed by a central entity (or a sink), which is responsible for collecting the congestion notification information that will be used to take the decision on congestion mitigation (the decision mitigation step is left for a future work). Additionally, we suppose that the network manager is aware of the network routing topolopy and each node is monitoring its buffer occupancy in order to notify the network manager. A threshold value θ is used by each node so that when buffer occupancy ratio is above θ, the node is considered as congested otherwise the node is

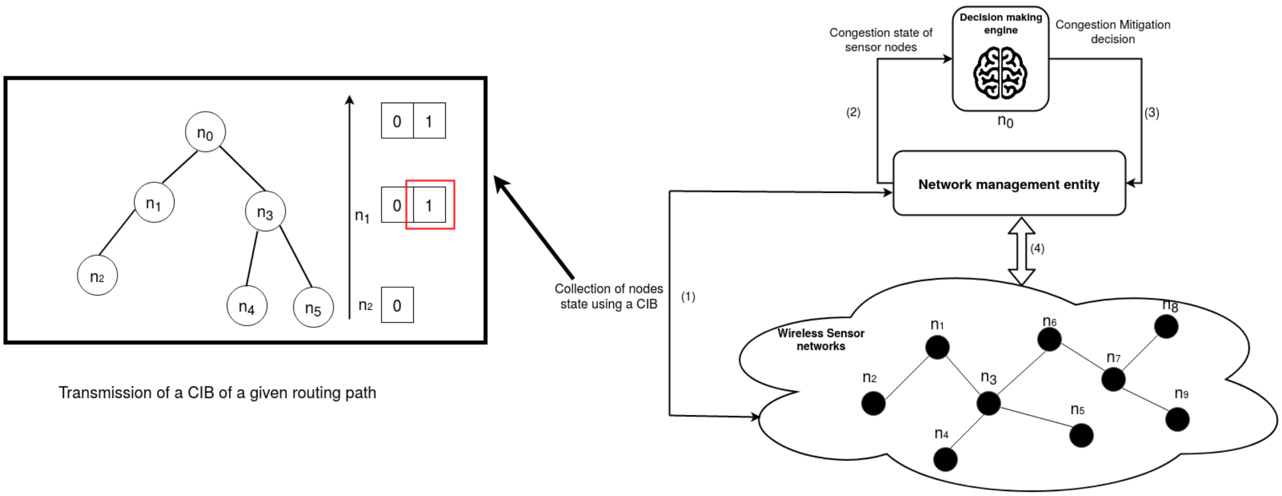


Fig. 1: Proposed architecture for congestion control in IoT low power networks.

not congested. The problem consists in providing an optimal method to notify the congestion state of nodes to the network manager while ensuring a good network performance.

B. Design of the proposed solution for congestion notification

In order to solve the above mentioned problem, we propose a novel scheme for congestion notification that allows to efficiently aggregate the congestion state of nodes in a given routing path into a block called Congestion Information Block (CIB). This scheme is designed to operate in an IoT low power network managed by a central entity, as shown in Figure 1. In the proposed architecture, the network management entity is responsible for collecting the congestion notification information in order to take the decision on congestion mitigation (based on a rule-based model or a machine learning model, etc). Thereby, our proposed scheme uses nodes buffer occupancy to infer the congestion state of a given routing path. The collection of nodes status information (buffer occupancy) is done hop-by-hop by using a CIB, as depicted in Figure 2.

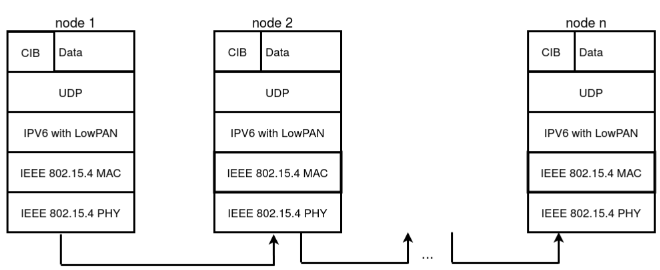


Fig. 2: IEEE 802.15.4 stack with a CIB.

Figure 1 also illustrates the transmission of the CIB toward the network manager. The transmission of the CIB is initiated by leaf nodes or by any intermediate node between the leaf and the network manager. The choice of the CIB initiators is left to the network manager. For each data packet to be sent to network manager, each node located in the routing path will insert its congestion state. The CIB is inserted into the payload of a data packet as depicted in Figure 3. According to the number of hops, the CIB may use a part or the whole field of the payload as shown by different scenarios in Figure 3. Typically, each node along the routing path inserts a binary value representing its Congestion Information (CI) in the packet payload according to the following rule:

$$CI = \begin{cases} 1 & if\, bufferOccupancy \geqslant \theta \\ 0 & if\, bufferOccupancy < \theta \end{cases} \quad (1)$$

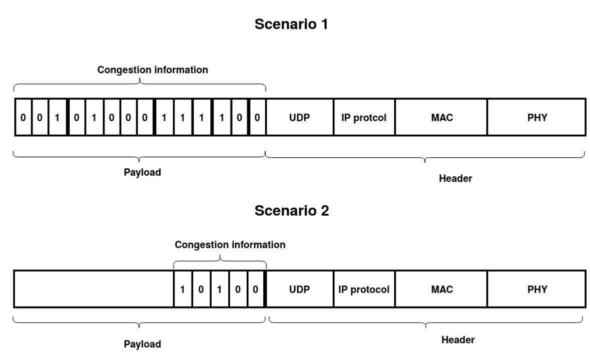


Fig. 3: Example of packets with CIB.

We provide in Figure 5 an overview of different operations related to CIB generation by leaf nodes. In Figure 6, we give an overview on operations executed by intermediate nodes after the reception of a packet with a CIB.

To process the CIB, the network manager verifies each binary value along with its index in the CIB. This way, all the nodes concerned by the congestion control decision will be identified by the manager based on the CIB indexes set to '1' (cf. Figure 4). It is worth to note that only nodes state and the id of the CIB generator (e.g., IP source address) are needed by the network manager in order to infer the network state. The congestion control decision may consist, for instance in

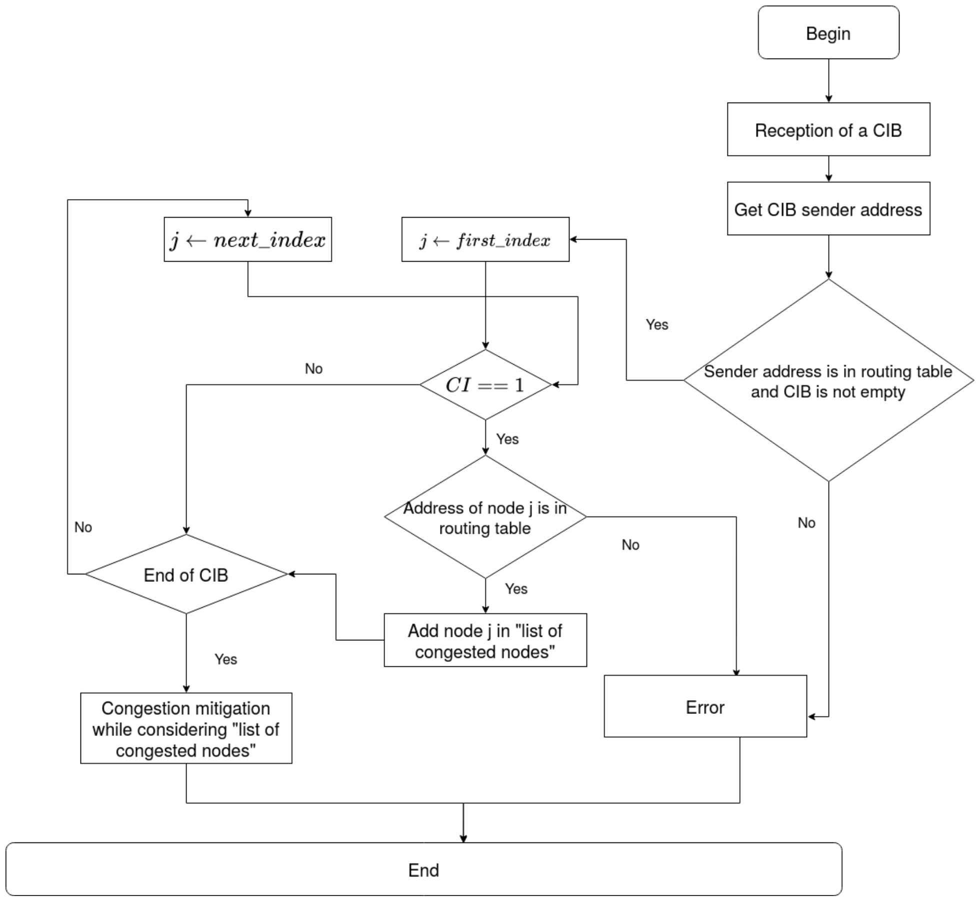


Fig. 4: Analyze of the CIB by the network manager.

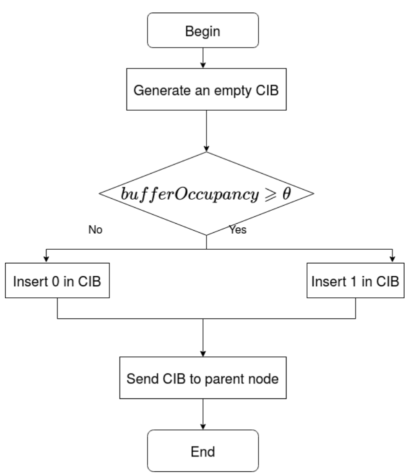


Fig. 5: Generation of a CIB by a leaf node.

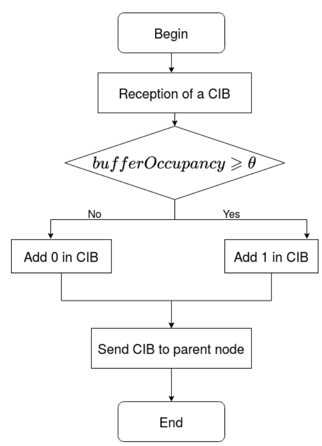


Fig. 6: Insertion of a CI into a CIB by an intermediate node.

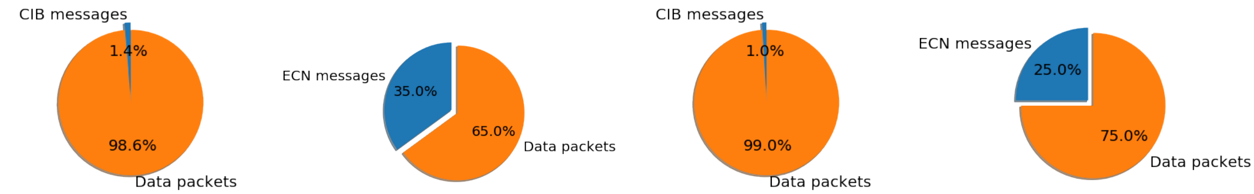
a reconfiguration of the routing table or an adjustment of the sending rate of nodes.

Compared to existing schemes such as ECN, ICN and INT, our proposed scheme for congestion notification generates very low overhead related to the collection of congestion states of nodes in IoT low power networks. In Table I, we provide a comparative summary of our solution with existing schemes according to different criteria.

IV. Simulation and Performance Evaluation

A. Simulation environment

We evaluated the performance of our solution for congestion notification by performing series of simulation in various scenarios using OMNeT++, an object-oriented modular discrete event simulator [15]. Moreover, we simulated



(a) CIB sending Interval = exponential (15ms) (b) ECN sending Interval = exponential (15ms) (c) CIB sending Interval = exponential (25ms) (d) ECN sending Interval = exponential (25ms)

Fig. 7: Traffic comparison.

TABLE I: Comparison of CIB with existing schemes.

	CIB	ECN	ICN	INT
Control data aggregation	yes	no	no	no
Implicit notification	yes	no	yes	yes
Network overhead	limited	yes	yes	yes

the realistic behavior of nodes using INET framework, an open-source OMNeT++ model suite for wired, wireless and mobile networks [16]. The INET framework contains a basic implementation of IEEE 802.15.4 protocol.

The main parameters used in the simulation are shown in Table II.

TABLE II: Simulation parameters.

Parameter	Value
Bitrate	100kps
Max queue size	50 packets
Number of Nodes	23
Number of ECN sources	22
Number of CIB sources	9
Data packet generation	exponential(8ms)
CIB/ECN generation	exponential(15ms), exponential(25ms)
Experiment duration	120s
Deployment area	1000m x 1000m

To evaluate the performance of our proposed scheme for congestion notification, we performed a comparison of our solution with ECN [6], a well known scheme for congestion notification.

B. Results and discussion

1) *Control messages overhead:* In Figure 7, we plotted the percentage of data packets and notification messages received by the network when varying the sending interval of CIB and ECN. Overall, our proposed scheme for congestion notification with CIB generates less control messages compared to ECN.
2) *Throughput:* Figure 8 and 9 show different throughput curves obtained when simulating CIB and ECN notification schemes with different sending intervals. The simulation results show that the throughput of CIB is lower than that of ECN.
3) *Divergence between congestion observed by the network manager and the real congestion state at nodes:* We measured the mean time necessary to notify the network manager that the state of node(s) changed. We observed that our proposed scheme for congestion notification is faster than ECN (cf. Figure 10).

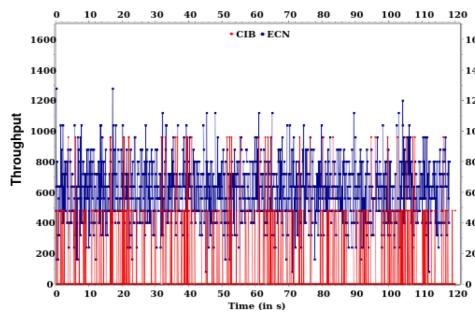


Fig. 8: Troughput comparison: sending interval of control messages = exponential 15ms.

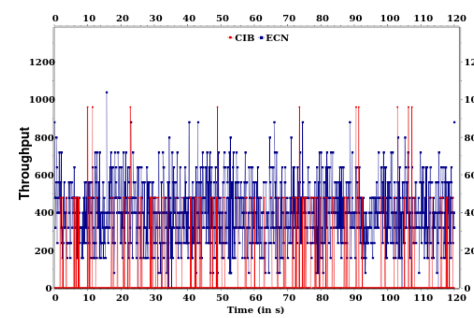


Fig. 9: Troughput comparison: sending interval of control messages = exponential 25ms.

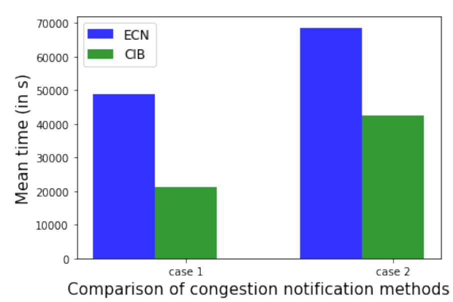


Fig. 10: Divergence between observed and real congestion states.

V. CONCLUSION

In this paper, we proposed a novel scheme for congestion notification in IoT low power networks. The proposed scheme allows to efficiently aggregate the congestion state of nodes in a given routing path into a single data packet by using a specific information structure called Congestion Information Bloc (CIB). This structure contains binary values representing the congestion state of nodes. The simulation results show that our proposed scheme performs well compared to ECN in terms of network throughput, control messages overhead and it offers low divergence between the congestion observed by the network manager and the real congestion of nodes. In our future work, we plan to extend our solution by integrating a congestion mitigation scheme and evaluate it in real IoT low power devices by considering more metrics, including energy consumption.

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