Towards Quality of Service for Long-range IoT in Unlicensed Radio Spectrum

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***Abstract*—The flexibility of long-range transmission comes at the cost of stricter legal regulations where duty-cycle approaches limits a transmitter to 1% duty-cycle in the general case. To provide better surveillance service guarantee we propose an activity time sharing mechanism for a pool of devices deployed by a single organization. Devices that need to go beyond the activity time limitation can borrow activity time from other devices. The proposed mechanism has been implemented as a library that can easily be integrated into existing projects.**

***Index Terms*—Long-range transmission, IoT, surveillance applications.**

I. Introduction

Recent modulation techniques where the long transmission distance (several kilometers even in NLOS conditions) can be achieved without relay nodes greatly reduces the complexity of deployment and data collection. Semtech's LoRa technology [1] is for instance attracting much attention from various Internet-of-Things actors. Such networks can be privately used and deployed following the recently proposed LoRaWAN™ specifications [2]. The flexibility of long-range transmission comes at the cost of stricter legal regulations where duty-cycle approaches limits a transmitter to 1% duty-cycle (i.e. 36s/hour) in the general case [3] where the time-on-air (ToA) of all transmitted messages should be taken into account. While this activity time may be largely enough for most of devices and for most of scenarios, still remains the issue of what to do when a device still needs to transmit critical information and has exhausted its allowed activity time in the current period of time, even when all possible optimization mechanisms have been applied (e.g. data aggregation, adaptive data rate,...). As these devices are mostly considered to be deployed for surveillance applications, this issue is highly important to address for providing quality of service guarantees: these devices can not simply stop transmitting nor violate deliberately the regulation.

In this paper we address the case of deploying a pool of remote devices, managed by a single organization under duty-cycle regulations. We propose to overcome the tight 36s/hour radio activity of a device by considering all the sensor's individual activity time in a shared/global manner. The approach we propose in this paper will allow a device that needs to go beyond the activity time limitation to borrow some from other devices to provide better surveillance service guarantee. A global view of the total activity time allowed per 1 hour cycle will be maintained at the gateway (Long-Range Base Station, LR-BS) so that each device knows the potential activity time that it can use in a 1-hour cycle.

The rest of the article is organized as follows. Section II presents the proposed mechanism that considers all the sensor node's individual activity time in a shared/global manner. Section III describes briefly additional issues for real deployment. We conclude in Section IV.

II. Long-range Activity Sharing (LAS)

An organization deploying a pool of n long-range devices can use up to a Global Activity Time of $G_{AT} = n \times D_{AT}$ per hour, where $D_{AT} = 36000ms$ (time is expressed in ms to avoid complex floating point variable coding). Then, the basic idea is to allow each long-range device to use up to G_{AT} and know its evolution over the 1-hour period.

A. Packet format

Our mechanism uses 3 control packet types between end-devices and the LR-BS: REG (register), INIT (initialization) and UPDT (update). The first byte, DSP, contains two 4-bit fields for flag indicators and packet type. We illustrate in Fig. 1 the packet format. l^i_{RAT} is device i's (noted D_i) local Remaining Activity Time while l^i_{RAT0} in a REG message is the initial local Remaining Activity Time announced by D_i to the LR-BS (most of the case $l^i_{RAT0} = D_{AT} = 36000ms$. r^i_{ATU} is D_i's local Remote Activity Time Usage. $|AT^i|$ and $E\{D_k\}$ in an UPDT message are respectively the Activity Time of D_i computed by the LR-BS and a list of device's id (address).

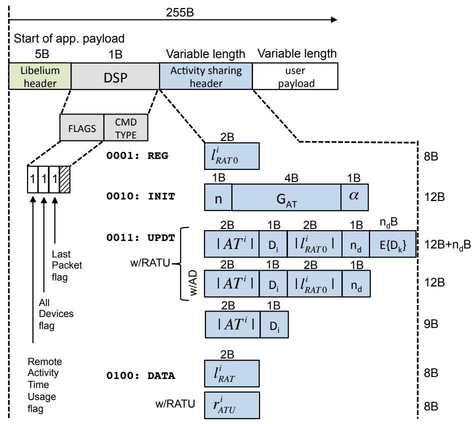

Fig. 1. Packet format

For a DATA packet, the RATU flag can be set to indicate whether the packet carries an l^i_{RAT} or an r^i_{ATU} coded in the first 2 bytes after the DSP byte. The LP flag indicates that it is the last packet in case the sender wants to send a serie of packets that should be seen as one transaction.

B. Proposed activity time sharing mechanism

We propose the usage of a centralized approach where the LR-BS updates G_{AT} on reception of packets from remote devices and will broadcast new values for G_{AT} at appropriate moment as it will be explained later on. We propose the following centralized radio activity sharing approach:

1) **Initialization**

1a) all deployed long-range devices D_i sharing their activity time initially register (REG packet) with the LR-BS by indicating their local Remaining Activity Time l^i_{RAT0}. The LR-BS stores all l^i_{RAT0} in a table (the last l^i_{RAT0} value, noted $lastl^i_{RAT0}$, will also be saved; initially $lastl^i_{RAT0} = l^i_{RAT0}$), computes G_{AT} and broadcasts (INIT packet) both n (the number of devices) and G_{AT}, see Fig. 2(left). Note that step 1.a is performed periodically every hour.

1b) on reception of n and G_{AT} from INIT message each device D_i can consider an initial (and locally managed) $G^i_{AT} = l^i_{RAT0} + \sum_{j=1, j\neq i}^{n} l^j_{RAT0}$, as shown in Fig. 2(right)(a). D_i also sets its local Remaining Activity Time, l^i_{RAT} (the green bar), to l^i_{RAT0} and both its local Total Activity Time, l^i_{TAT}, and its remote Activity Time Usage, r^i_{ATU}, to 0.

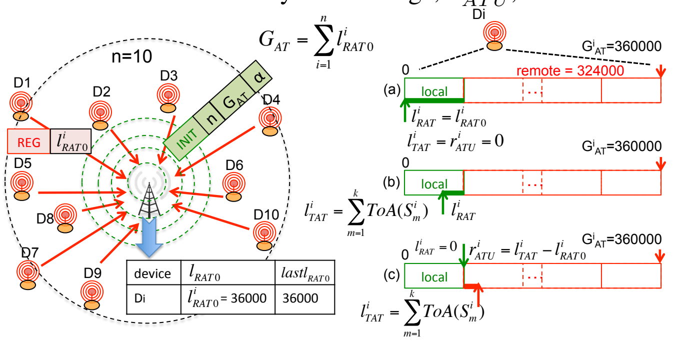

Fig. 2. Left: initialization. Right: device's local and remote activity time

2) **Device D_i wants to send a DATA packet k of size S^i_k**

2a) D_i computes $ToA(S^i_k)$.

2b) if $l^i_{TAT} + ToA(S^i_k) > \alpha \times G^i_{AT}$ then ABORT.

2c) D_i updates $l^i_{TAT} = l^i_{TAT} + ToA(S^i_k)$ and $l^i_{RAT} = l^i_{RAT} - ToA(S^i_k)$, see Fig. 2(right)(b).

2d) if $l^i_{TAT} > l^i_{RAT0}$ then D_i sets $l^i_{RAT} = 0$ and $r^i_{ATU} = l^i_{TAT} - l^i_{RAT0}$ (the red bar), see Fig. 2(right)(c).

2e) if $r^i_{ATU} > 0$ puts r^i_{ATU} in data packet and sets the Remote Activity Time Usage (RATU) flag; otherwise, puts l^i_{RAT} in data packet.

3) **LR-BS receives a DATA packet k from D_i of size S^i_k**

3a) LR-BS computes $ToA(S^i_k)$ and updates for device D_i $l^i_{RAT0} = l^i_{RAT0} - ToA(S^i_k)$.

3b) when last packet or timeout from D_i computes $AT^i = l^i_{RAT0} - lastl^i_{RAT0}$.

3b.1) if $l^i_{RAT0} > 0$, broadcasts an UPDT message indicating $|AT^i|$ and D_i's id.

3b.2) if $l^i_{RAT0} < 0$, then determines how many devices, n_d, should take over the extra activity time consumed by device D_i and broadcasts an UPDT message with a Remote Activity Time Usage (RATU) flag indicating $|AT^i|$, D_i, $|l^i_{RAT0}|$, n_d and a list of device's id. If $lastl^i_{RAT0} < 0$ then $|AT^i|$ is replicated in the $|l^i_{RAT0}|$ field as D_i had already consumed all its local activity time. For the selected devices j, the LR-BS updates their l^j_{RAT0} (stored in the table) accordingly, $l^j_{RAT0} = l^j_{RAT0} - |l^i_{RAT0}|/n_d$, and sets $lastl^j_{RAT0} = l^j_{RAT0}$.

3b.3) if an UPDT message has been sent, saves the current value of l^i_{RAT0} into $lastl^i_{RAT0}$.

4) **Device D_j receiving an UPDT from LR-BS**

4a) if $j \neq i$ then D_j updates $G^j_{AT} = G^j_{AT} - |AT^i|$.

5) **Device D_j receiving an UPDT w/RATU from LR-BS**

5a) if $D_j \in E\{D_k\}$, takes the advertised $|l^i_{RAT0}|$ and updates $l^j_{TAT} = l^j_{TAT} + |l^i_{RAT0}|/n_d$, $l^j_{RAT} = l^j_{RAT} - |l^i_{RAT0}|/n_d$ and $G^j_{AT} = G^j_{AT} - |AT^i| + |l^i_{RAT0}|$ because all D_j in list of devices contribute to $|l^i_{RAT0}|$.

5b) if $D_{j\neq i} \notin E\{D_k\}$, updates $G^j_{AT} = G^j_{AT} - |AT^i|$ because it has to remove what has been consumed by D_i.

The main work is done by the LR-BS with action 3.b which determines the Activity Time consumed by a device D_i. While $l^i_{RAT0} > 0$ only local activity time is used so UPDT messages only trigger at $D_{j\neq i}$ action 4.a which only decreases G^j_{AT}. This is illustrated in Fig. 3 where D_4 uses 20896ms of its local activity time. As can be seen in the figure, for any device D_k the green arrow (l^k_{RAT}) and the red arrow (local G^k_{AT}) delimit the amount of total allowed activity time for that device.

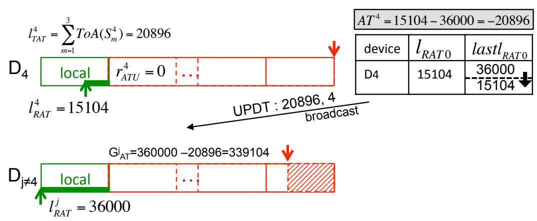

Fig. 3. Local activity time consumption

The LR-BS keeps track of consumed activity time when receiving a packet from a device D_i. However, to make the system more robust to packet losses, the data packet header includes for device D_i the value of either l^i_{RAT} or r^i_{ATU}, depending on the RATU flag in the packet header. This is the purpose of action 2e. Although not shown, action 3a includes a comparison between the l^i_{RAT} indicated in the packet and the l^i_{RAT0} stored by the LS-BR. A different value means that there have been some packet losses.

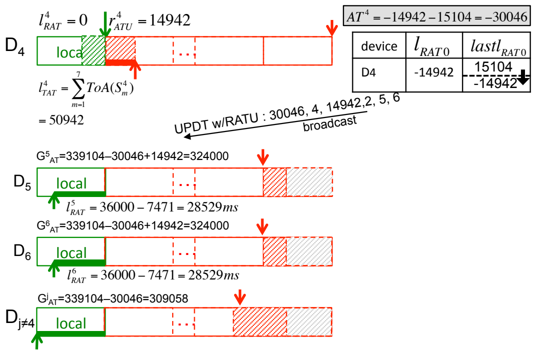

Fig. 4. Remote activity time consumption

In Fig. 4, we illustrate the case where device D_4 continues transmitting, uses all his allowed local activity time, i.e. 36000ms, and also used $r^4_{ATU} = 14942ms$ from the remote activity time pool. Therefore, when the LR-BS received the last packet from D_4, $AT^4 = -30046ms$ according to action 3b. The LR-BS will decide, in the example, to assign to devices D_5 and D_6 the role of supporting the extra activity time consumed by D_4. Therefore the UPDT message with the RATU flag starts with the value of $|AT^4| = 30046ms$ followed by D_4's id, $n_d = 2$, $|l^4_{RAT0}| = 14942$ from the table and finally D_5 and D_6 ids. D_5 and D_6 will each remove 7471ms from l^5_{RAT} and l^6_{RAT} respectively. If we assume that both devices did not send any message, then $l^5_{RAT} = l^6_{RAT} = 28529ms$. They then update their local value of $G^{5,6}_{AT}$ by removing AT^4, but adding $|l^4_{RAT0}|$ because both of them already contributed previously to $|l^4_{RAT0}|$, action 5a. Therefore, at the end, they both have their $G^{5,6}_{AT}$ decreased by D_4's whole allowed local duty-cycle. A device $D_{j\neq i}$ and not in the selected device list has to remove from its local value of G^j_{AT} the totality of what has been consumed to have a consistent view for G_{AT}, action 5b.

III. Additional Issues

We describe briefly additional issues that have been implemented for real world deployment.

A. *Support for sleep period of end-devices*

For the synchronized radio wake-up mechanism the LR-BS broadcast periodically all the UPDT messages that have been generated and queued for transmission, if any. As a consequence, end-devices need to wake up periodically to look for UDPT messages if any. When receiving UPDT messages, each device apply them sequentially.

B. *Reduce UPDT message traffic sent by the LR-BS*

It is possible to reduce the LR-BS radio activity time for UPDT messages to a minimum by exploiting their cumulative behavior. For instance, at the end of a serie of transmissions from device D_k, if a regular UPDT message $(|AT^k|, D_k)$ needs to be sent, the LR-BS actually only set a `needUpdate` flag in the device table for device D_k. The UPDT message will be sent later on, after several cumulative local updates.

C. *Increase of the LR-BS allowed transmission time*

The LR-BS can borrow activity time of end-devices in a simple way: the $|AT^i|$ and $|l^i_{RAT0}|$ field of an UDPT w/RATU message can both be increased by the ToA of the UPDT message itself so that other end-devices k will remove the additional ToA of the UPDT message from their l^k_{RAT}.

D. *Increase efficiency and reliability of LoRa networks*

Most of current LoRa network deployment is based on pure ALOHA access to the shared radio medium. We propose to use LBT in conjunction of a priority mechanism similar to the inter-frame spacing (IFS) mechanism of IEEE 802.11: Distributed IFS ($DIFS$) and Short IFS (IFS) where $SIFS < DIFS$. The LBT mechanism is based on both RSSI and the Channel Activity Detection (CAD) feature offered by the SX1272 LoRa chip. Prior to send a DATA packet, an end-device should see a free channel for at least a $DIFS$ (we will refer to this case as a $DIFS_{CAD}$). If it is the case RSSI measures acquired while performing CAD is additionally checked. If the RSSI is below a given threshold, the packet is transmitted. Otherwise the device waits for a random number of $DIFS$ without performing CAD and the channel attempt process is restarted. To support transaction-like transmission, the first DATA packet of a serie uses the $DIFS$, all following packets until the last one will use $SIFS$. All control messages sent by the LR-BS use the $SIFS$: INIT and UPDT messages will therefore have higher priority.

IV. Conclusions

While long-range radio is a promising technology to boost deployment of IoT, current deployed networks do not provide any quality of service mechanism to ensure that a device that needs to send critical data will be able to so without being limited by the regulations. To go one step towards quality of service for long-range IoT, we proposed an activity time sharing mechanism in scenarios where a pool of devices are deployed by a single organization. The proposed mechanism has been implemented as a library that can easily be integrated into existing projects.

Acknowledgments

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