TSTP MAC: a Cross-Layer, Geographic, Receiver-Based MAC Protocol for WSNs

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***Abstract*—In Wireless Sensor Networks (WSNs), energy saving is a big concern. Radio transceivers are a major source of energy consumption and it is generally desirable to turn them on for just a fraction of the time, but this brings a trade-off between energy saving and latency and/or node availability. TSTP MAC is a cross-layer Medium Access Control protocol which is part of TSTP – an application-oriented network solution for WSNs. It handles collision avoidance, acknowledgement, duty cycling and greedy, fully-reactive geographic routing. With a delay of 116ms, TSTP MAC is able to achieve a receiver duty cycle of 1% while still letting nodes always be available for data reception.**

***Keywords*-Wireless Sensor Networks; MAC; Protocol; Cross-Layer; Geographic; Routing**

I. Introduction

It is a challenge to provide low-latency, reliable data delivery and energy efficiency in such resource-constrained, dynamic networks as Wireless Sensor Networks. Since idle listening is the main source of energy dissipation in WSNs [4], *duty cycling* is a solution generally used to reduce the energy usage of nodes. It consists of letting sensor nodes spend most of their time in sleep mode and wake up to listen to the channel for a relatively short duration every period CI (Checking Interval).

The *Trustful Space-Time Protocol* (TSTP) [3] is an application-oriented, cross-layer protocol for WSNs which focuses on efficiently delivering functionality recurrently needed by WSN applications: trusted, timed, geo-referenced, SI-compliant data that is resource-efficiently delivered to a sink. TSTP makes all the nodes aware of their spatial and temporal localization, and uses geographic routing to deliver data. In this extended abstract, we present with greater detail TSTP MAC, the Medium Access Control (MAC) part of TSTP.

TSTP MAC runs directly on top of an IEEE 802.15.4 2450MHz DSSS PHY layer. It is a cross-layer MAC protocol based on RB-MAC [1] [4] which handles collision avoidance, acknowledgement, duty cycling and greedy geographic routing.

II. Related Work

In Receiver-Based MAC (RB-MAC) [1], senders transmit data without defining a particular node as receiver. The final destination is a pre-defined sink. Since nodes only wake up from time to time, transmitters send a long preamble before the payload to make sure that every node will wake up in time to detect the transmission.

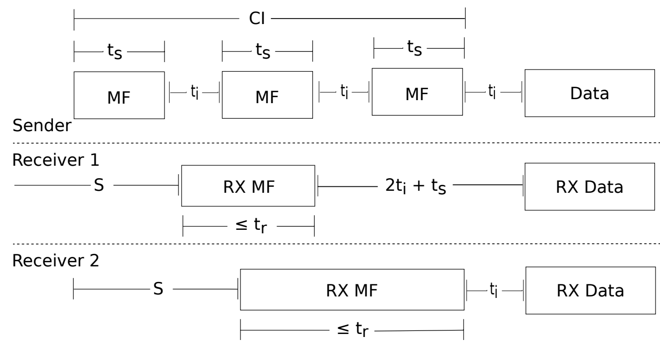

Figure 1: TSTP MAC transmission example with 3 Microframes ($N_{MF} = 3$). Receiver 2 might wake up late due to clock drift and miss the first Microframe, but it receives the second one if $t_r \geq 2t_s + t_i$.

Preambles consist of Microframes (MF) that contain useful information such as countdown to data transmission, sender distance to sink and payload sequence number. All neighboring nodes within communication range of the sender sense the channel every CI interval, obtain a Microframe and extract the information; then, only eligible receivers (nodes closer to the sink) go back to sleep and wake up to receive the data at the time indicated by the countdown. Nodes that receive the data without error are relay candidates, and start a back-off timer based on their own distance to the sink and possibly other factors (e.g. remaining energy), which when elapsed will trigger a channel check (CCA). The node with the shortest back-off timer will sense no channel activity and proceed to transmit the preamble for CI units of time. Other relay candidates will detect the winner's preamble containing the same sequence number, drop the data and go back to sleep since the packet is already being forwarded. The Microframes also serve as a passive acknowledgment to the previous sender of the message. As a consequence of the way relay candidates are determined, packets are geographically routed to the final destination in a greedy way. Figure 1 illustrates a message transmission.

RB-MAC is significantly more resilient to lossy links when compared to sender-based MAC protocols (in which sender nodes keep the addresses of perceived neighbors and define a

Microframe					
Bits: 1	**8**	**32**	**15**	**16**	
All Listen	Count	Last Hop distance	ID	FCS	} 9 octets

Figure 2: TSTP MAC Microframe format.

receiver) [4]. As the number of network nodes increases, RB-MAC requires fewer retransmissions, consequently reducing latency and energy consumption [4].

In [2], the author presents and analyses the ContikiMAC protocol, which is also implemented on top of IEEE 802.15.4. The author analyses timing constraints based on the standard and presents a derivation of possible network parameters such as Microframe size, CCA time and duty cycle. ContikiMAC reaches a duty cycle of roughly 1% for CI values around $125ms$. In this work, we present a similar analysis for TSTP MAC.

III. TSTP MAC

TSTP MAC follows the general principles of RB-MAC presented in Section II. Figure 2 shows the Microframe format. The *All Listen* and *ID* fields are explained in [3], and the FCS field is used for error detection.

A. Definitions

$d \in (0, 1]$	Receiver duty cycle
$s_r = 62.5 \frac{symbol}{ms}$	IEEE 802.15.4 Symbol Rate
$T_u = \frac{12}{s_r} = 0.192ms$	IEEE 802.15.4 Turnaround Time
$S_{MF} = 30symbol$	Microframe and PHY header size
$t_s = \frac{S_{MF}}{s_r} = 0.48ms$	Time to transmit a Microframe
$t_r = CI \times d$	Microframe listening time
$S = CI - t_r$	Receiver sleeping time
$N_{MF} \geq 1$	Number of Microframes
$t_i \geq T_u$	Time between Microframes

B. Microframe and Data transmission

Before transmitting a message, a sensor checks for channel activity to avoid collisions. If the message is new (i.e. not a forwarding), the back-off Bkf shall be random and a multiple of the time gap g between a transmitter sensing an available channel and finishing transmission of enough symbols for other nodes to sense a busy channel (8 symbols in IEEE802.15.4). Bkf shall not exceed S, to make sure that receivers will not miss the Microframes of an ongoing transmission (Equations 1,2).

$$g = T_u + 8/s_r \tag{1}$$

$$Bkf = random\left(\left\lfloor \frac{S}{g} \right\rfloor\right) \times g \tag{2}$$

If the message is not new, this sensor is currently trying to forward it, and the back-off serves to elect the forwarder among all the candidates [1]. Instead of delaying randomly, the sensor sets the back-off as being directly proportional to its distance to the destination, according to Equation 3.

$$Bkf = \left\lfloor \frac{|D - (D_{msg} - R)|}{gR/S} \right\rfloor \times g \tag{3}$$

where D is the node's distance to the message's destination, D_{msg} is the distance to the destination from the last node to transmit this message (taken from the Microframe) and R is a fixed network parameter representing the nodes' radio range.

If after the back-off the node detects no channel activity, it starts transmitting N_{MF} Microframes with a t_i delay between them, occupying a total time CI (Figure 1). The *Count* field (Figure 2) reflects how many Microframes are left until the transmission of the corresponding Data payload.

If the sensor is not the final destination, it proceeds with transmission of the Data. If no further Microframes from this ID are received until a given timeout, the sensor assumes that no other node received the message and shall retransmit.

C. Microframe and Data Reception

When a Microframe is received, the sensor checks if it has a valid FCS and $D_{msg} > D$ (i.e. the node that is transmitting it is farther from the destination than this node). If so, the sensor sleeps for S' (Equation 4) and proceeds to receive the corresponding Data.

$$S' = t_i + Count \times (t_i + t_s) \tag{4}$$

IV. Determination of parameters

To find N_{MF} and the best possible d for a given CI, we start by considering $t_i = T_u$ (the minimum possible value of t_i), then find a fractional N'_{MF}. Since N_{MF} needs to be integral, we use $N_{MF} = \lfloor N'_{MF} \rfloor$ (so that $t_i \geq T_u$ will still hold) and, finally, find t_i, t_r and d from CI and N_{MF}:

$$\begin{aligned} N_{MF} &= \left\lfloor 1 + \frac{CI - t_s}{T_u + t_s} \right\rfloor \quad (a) \qquad t_r = 2t_s + 2t_i \quad (c) \\ t_i &= \frac{CI - t_s}{N_{MF} - 1} - t_s \quad (b) \qquad d = \frac{t_r}{CI} \quad (d) \end{aligned} \tag{5}$$

When $CI \geq 116ms$, $d \leq 1\%$.

V. Conclusion

In this extended abstract, the Medium Access Control part of the Trustful Space-Time Protocol was described, with an analysis of timing constraints and parameter determination. With a user-defined network delay of at least $116ms$ per hop (comparable to ContikiMAC's $125ms$), TSTP MAC allows receivers to keep their radios turned off for roughly 99% of the time and yet receive and geographically route every message that reaches them.

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