CISTER
Research Centre in
Real-Time & Embedded
Computing Systems

Demo

Demonstrating RA-TDMAs+ for robust communication in WiFi mesh networks

Diogo Almeida
Miguel Gutiérrez Gaitán*
Pedro d'Orey*
Pedro Miguel Santos*
Luis Pinto
Luís Almeida*

*CISTER Research Centre

CISTER-TR-211007

2021/12/07

Demonstrating RA-TDMAs+ for robust communication in WiFi mesh networks

Diogo Almeida, Miguel Gutiérrez Gaitán*, Pedro d'Orey*, Pedro Miguel Santos*, Luis Pinto, Luís Almeida*

*CISTER Research Centre

Rua Dr. António Bernardino de Almeida, 431

4200-072 Porto

Portugal

Tel.: +351.22.8340509, Fax: +351.22.8321159

E-mail: up201805400@edu.fc.up.pt, mjggt@isep.ipp.pt, ore@isep.ipp.pt, pss@isep.ipp.pt, pin@isep.ipp.pt, lda@fe.up.pt

https://www.cister-labs.pt

Abstract

This work will demonstrate a new flavor of the RA-TDMA set of protocols, namely RA-TDMAs+, which uses IEEE-802.11 (WiFi) COTS hardware in ad-hoc mode to set up a dynamic mesh network of mobile nodes with high-bandwidth. The protocol uses topology tracking to configure the TDMA frame and robust relative synchronization to define the TDMA slots without resorting to a global clock and in the presence of interfering traffic. The demo will set up a small-scale testbed using COTS hardware, thus evidencing the feasibility of the approach, and it will show 1clive plots 1d of the temporal (synchronization) and topological views of the network.

Demonstrating RA-TDMAs+ for robust communication in WiFi mesh networks

Diogo Almeida†, Miguel Gutiérrez Gaitán†‡§*, Pedro M. d'Orey‡, Pedro M. Santos‡, Luís Pinto¶ and Luís Almeida†‡

‡ CISTER - Research Centre in Real-Time and Embedded Computing Systems, Porto, Portugal

† Universidade do Porto, Porto, Portugal

§Universidad Andrés Bello, Santiago, Chile

¶Instituto Superior Técnico, Lisbon, Portugal

Email: up201805400@edu.fc.up.pt, {mjggt, ore, pss}@isep.ipp.pt, lpinto@ipfn.tecnico.ulisboa.pt, lda@fe.up.pt

***Abstract*—This work will demonstrate a new flavor of the RA-TDMA set of protocols, namely RA-TDMAs+, which uses IEEE-802.11 (WiFi) COTS hardware in ad-hoc mode to set up a dynamic mesh network of mobile nodes with high-bandwidth. The protocol uses topology tracking to configure the TDMA frame and robust relative synchronization to define the TDMA slots without resorting to a global clock and in the presence of interfering traffic. The demo will set up a small-scale testbed using COTS hardware, thus evidencing the feasibility of the approach, and it will show "live plots" of the temporal (synchronization) and topological views of the network.**

***Index Terms*—IEEE 802.11, synchronization, TDMA, topology tracking, wireless networks, Wi-Fi.**

I. Introduction & Motivation

Cooperative autonomous agents, e.g., mobile robots or sensor nodes, often rely on ad-hoc networks to support distributed real-time applications. IEEE 802.11 (WiFi) is commonly used as ad-hoc network when the agents exchange high-bandwidth data flows, e.g. video streams. Carrier-Sense Multiple Access with Collision Avoidance (CSMA/CA) is the underlying method for dealing with nodes' concurrent transmissions through a shared medium. However, this contention-based mechanism does not guarantee a predictable timing behavior. An overlay Time-Division Multiple Access (TDMA) frame built on top of CSMA/CA can be used to improve predictability, effectively reducing channel contention. However, in dynamic mesh networks, e.g., with mobile agents, setting up a TDMA frame requires topology tracking and synchronization.

The Reconfigurable and Adaptive TDMA protocol for streaming on dynamic mesh networks, namely RA-TDMAs+, uses fully distributed topology tracking and relative synchronization services. The former allows keeping the TDMA frame configured for the current topology, while the latter allows defining the TDMA slots boundaries. The *relative* (clockless) synchronization adapts dynamically the slots boundaries to delay variations based on packet receptions. This is particularly suited to dynamic mesh networks in the presence of interfering traffic, e.g., external to the network and not conforming to the TDMA frame, increasing the robustness of the synchronization. This demonstration will show RA-TDMAs+ in action, focusing on the topology tracking and relative synchronization services, using WiFi COTS hardware.

II. Prior Work & Contribution

This demo leverages the set of RA-TDMA protocols developed previously for communications within teams of mobile autonomous agents, namely RA-TDMA+ [1] for ad-hoc mesh networks and the synchronization mechanism of RA-TDMAs [2] for streaming over line networks. From the former [1], we use the topology tracking mechanism, which however was designed for low bandwidth communication and relies on a single packet sent by every node at the beginning of its own slot for synchronization. Conversely, the latter [2] was conceived specifically for line topologies with high-bandwidth. It has an enhanced synchronization mechanism that harnesses the delays of all packets transmitted by every node to achieve synchronization, making it more robust. RA-TDMAs+, that we are demonstrating now, uses the topology tracking of [1], as needed in mesh networks, and combines it with the synchronization of [2] that is more robust and suitable for streaming applications. This modification required a careful analysis of the multiple sources of synchronization in a mesh context and their adequate combination to determine the adaptation of the slots in a consistent and convergent way.

III. TDMA Synchronization Framework

Topology tracking. In a dynamic mesh the set of nodes and their connections, i.e., the topology, are always changing. Knowing the topology is necessary to configure the overlay TDMA frame, particularly the number and order of the slots.

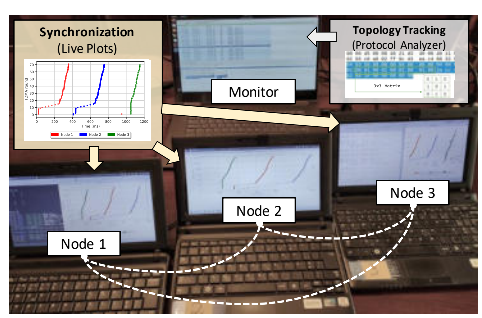
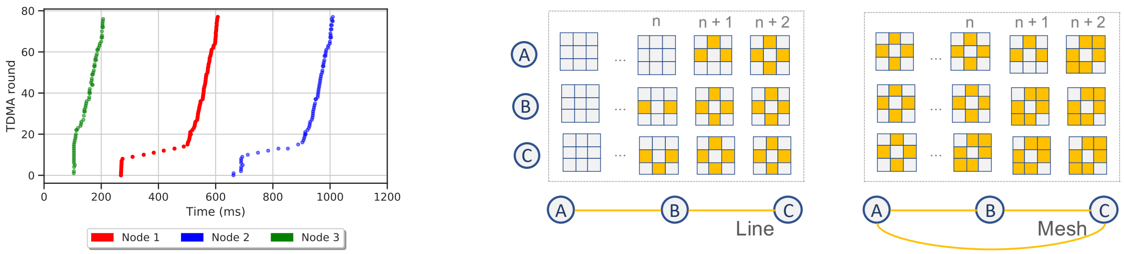


Fig. 1: Experimental setup composed of three nodes with programmable connectivity among them and an additional monitor node.



(a) Demo 1: Node synchronization.

(b) Demo 2: Topology Tracking.

Fig. 2: Examples of the expected views of the (a) temporal and (b) topological views of the network when using RA-TDMAs+.

In a given node k we represent the topology by a square matrix M^k, where $M^k(i,j)$ indicates the connectivity between the nodes i and j. This matrix is broadcast at every transmission round, together with a vector of sequence numbers s^k. Before every transmission the element k in vector s^k ($s^k(k)$) is incremented. When node k receives the matrix (M^j, s^j) of node j it updates its own matrix M^k. It sets the element j of line k ($M^k(k,j)$) representing the $j \rightarrow k$ connection and it replaces all the remaining lines with the corresponding ones in M^j that have higher sequence number, thus more recent, i.e., $\forall_{i \neq k}$ if $s^j(i) > s^k(i)$ then $M^k(i) = M^j(i)$.

Node synchronization. After knowing the TDMA frame configuration of the current topology, the synchronization mechanism allows determining the slot boundaries in each node. This is based on relative timestamps that are piggybacked on all packets, with the respective time offset of the transmission w.r.t. the start of the transmitter slot. At the receiver side, the node assesses the delay between the expected and effective arrival times for each packet. The delays of all packets received in a TDMA round are combined with an adequate function and the result, if positive and up to a certain limit, is used to adjust the start of its own transmission slot. In the absence of receptions or negative delays, i.e., packets arriving earlier than expected, no adjustment is performed.

IV. Demonstration

Setup. We consider a small-scale testbed in a laboratory environment consisting of 3 nodes running the RA-TDMAs+ protocol as shown in Fig. 1. Each node is a conventional laptop using a Linux Operating System (OS) and equipped with an in-built 802.11 b/g/n antenna. An additional node (*monitor*) is co-located to the other nodes and captures all network traffic using Wireshark. This node uses a wireless interface card configured in *monitor* mode in the defined WiFi channel.

Demo 1. This experiment will demonstrate the functioning of the synchronization mechanism. It will display the evolution of the time boundaries of each node's slot, with their dynamic adjustment as function of the locally perceived delays affecting the received packets. We will show adjustments caused by topology changes and by external interference. An example of the expected output is presented in Fig. 2a showing the local view of the TDMA slots boundaries seen by one of the nodes and its evolution with the synchronization process (evolves upwards in the figure). The figure shows that nodes are not synchronized during the first few rounds (lower area), but, as time passes (moving up the plot), nodes 1 and 2 shift the start of their slots until all nodes converge to equal slot duration (400 ms in this case). As convergence is reached, the temporal spacing is maintained until there is again a topology change or external interference.

Demo 2. This experiment will show the operation of the topology tracking service by displaying the topological view of the network at each node as it evolves over time, highlighting its (fast) convergence speed. Since nodes are all in range, the network topology is imposed by software by discarding packets from links that are considered broken. In our demo we start the experiment with two nodes, only. Then, we add a third node in a line topology – see Fig. 2b (left). Then, we connect all of nodes together to create a fully connected mesh – see Fig. 2b (right). We will show graphically the contents of the topology matrices in all nodes and their evolution when the topology changes. We will also use the Wireshark at the monitor node to show the contents of the packets.

V. Conclusion

This demo introduces RA-TDMAs+, a new variant of the RA-TDMA family protocols enabling high-bandwidth data streams on dynamic WiFi mesh networks. We will set up a small-scale testbed to demonstrate the feasibility of the approach using inexpensive WiFi COTS hardware. We will demo the functioning of the topology tracking and robust (relative) synchronization services, which are key to maintain temporal and topological consistency among network nodes.

Acknowledgment

This work was partially supported by National Funds through FCT/MCTES (Portuguese Foundation for Science and Technology), within the CISTER Research Unit (UIDB/04234/2020); by the Operational Competitiveness Programme and Internationalization (COMPETE 2020) under the PT2020 Agreement, through the European Regional Development Fund (ERDF); also by FCT and the ESF (European Social Fund) through the Regional Operational Programme (ROP) Norte 2020, under PhD grant 2020.06685.BD; and within the AQUAMON project (PTDC/CCI-COM/30142/2017).

References

[1] L. Oliveira, L. Almeida, and D. Mossé, "A clockless synchronisation framework for cooperating mobile robots," in *2018 IEEE Real-Time and Embedded Technology and Applications Symposium (RTAS)*, pp. 305–315, IEEE, 2018.

[2] L. R. Pinto and L. Almeida, "A robust approach to TDMA synchronization in aerial networks," *Sensors*, vol. 18, no. 12, p. 4497, 2018.