A real-time low datarate protocol for cooperative mobile robot teams

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I. Introduction

Mobile cooperating robot teams are increasingly used in several applications, for instance, to access and explore dangerous areas for humans (e.g., nuclear plants, minefields or volcanoes). As in these applications the mobile robots have to communicate in order to cooperate and fulfill a common task, communication plays a key role and has to meet the requirements imposed by the applications [1], i.e., bounded end-to-end delays, mobility support, high scalability, and low costs. Recent works investigate the combination between cooperating mobile robot applications and Wireless Sensor Networks (WSNs), e.g., applications in which mobile robots are considered the mobile sensors of a WSN [2]. This demo presents RoboMAC, a new MAC protocol for communicating between mobile cooperating robots. RoboMAC enables the integration of robots with WSNs, supports real-time communications and mobility, and provides high scalability. RoboMAC was implemented on the STMicroelectronics SPIRIT1 Sub-GHz devices, which operate on less crowded frequencies than the other Industrial, Scientific and Medical (ISM) ones and provide a higher radio coverage.

The main contributions of RoboMAC are summarized below.

- It enables the integration of robots with WSNs, being specifically devised for low datarate communications.
- It provides support to mobility, combining clustering with a distributed topology management mechanism based on Received Signal Strength Indicator (RSSI) assessments.
- It provides scalable real-time communications thanks to the combination of a TDMA-based mechanism with multichannel transmissions and clustering.

II. Overview on the RoboMAC Protocol

As mentioned in the Introduction, the RoboMAC protocol aims to provide bounded delays, mobility support, scalability, and low cost. The way RoboMAC achieves each of these properties is described in the following.

A. *Bounded delays*

To provide bounded delays, a TDMA transmission scheme is implemented, in which the time is divided into superframes, which are cyclically repeated. Each superframe is, in turn, divided into slots. A node is assigned one or more slots in which it is allowed to transmit a single frame. In RoboMAC each node schedules its messages according to their priority. Here static priorities are assumed, which derive from and depend on the application. In Fig. 1. The RoboMAC node architecture is shown. The MAC layer provides two sublayers, i.e., the Medium Access and Synchronization sublayer and the Clustering and Routing one. The upper sublayer communicates with the lower one through two prioritized queues (i.e., the IntraCluster and the InterCluster PrioQueue, respectively) for the frame transmissions, and one FIFO queue for the incoming frames.

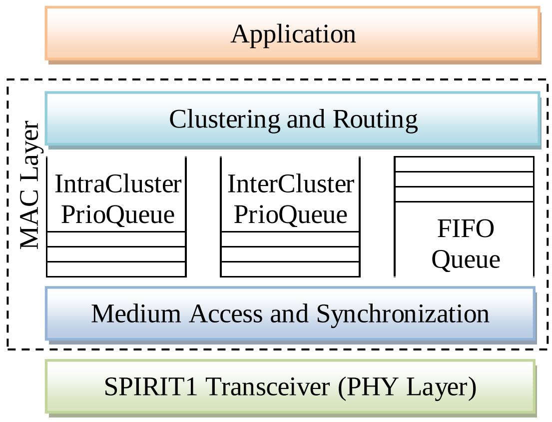

Figure 1 Node architecture

Node synchronization is achieved by taking into account the transmission time of other nodes. As the start time of a frame transmission is known to all the network nodes, when a node receives a frame it calculates the difference between the expected reception time of the first byte of the frame and the actual time at which such a byte is received. Such a value is the time difference between the two nodes. If the frame is received outside a guard interval, it is not taken into account for the synchronization. The guard interval is the same for all the network nodes and it depends on the maximum synchronization skew supported by the application.

B. *Scalability*

To efficiently support large networks, in RoboMAC the nodes are organized in clusters, depending on their position in the network (i.e., the nodes that are close to each other belong to the same cluster). During the network initialization, the position of network nodes is estimated by exchanging a matrix containing the Received Signal Strength Indicators (RSSI), which holds the link relations between the nodes. In this way the nodes are aware of the network topology. Two transmission channels are used, one for intracluster communications, the other for intercluster ones. Intercluster communications are allowed between the nodes of two clusters when the relevant clusters do not have on-going intracluster communications.

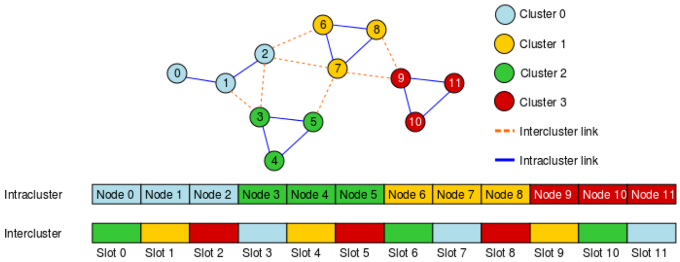

Figure 2 RoboMAC network example.

Looking at the example in Fig. 2, during the slots assigned to the Cluster 2 nodes (i.e., Nodes 3, 4, and 5), the nodes of Clusters 0, 1 and 3 can communicate on a different channel provided that the message destination does not belong to Cluster 2. Intercluster slots are assigned to the nodes in turn.

C. *Mobility support*

RoboMAC provides dynamic clusters, so their composition varies over time. In fact, due to the mobility, the distances change, and so the RSSI. For this reason RoboMAC provides a distributed topology management, which is based on the RSSI that is regularly acquired during the communications. Mobility issues, like the unpredictability of the network topology, are solved transmitting either intercluster or intracluster topology information within the header of each frame.

D. *Low cost*

The RoboMAC protocol has been implemented on the STMicroelectronics STEVAL-IKR002V5 [3] board (Fig. 3), a commercial-off-the-shelf device available at low cost.

III. The Demo

The demo presents the RoboMAC protocol implementation on the STMicroelectronics STEVAL-IKR002V5 board, which is composed of a motherboard equipped with a STM32L1 family microcontroller (MCU) and the SPIRIT1 transceiver, which operates at 915MHz and provides a datarate of 250kbps. The communication between the MCU and the transceiver goes through the SPI port, which operates at 1Mbps.

The slot duration is configured so as to accommodate the delays caused from the communication between the transceiver and the MCU, the channel switching time, and the transmission delay.

The demo will show the protocol in a scenario made up of 5 nodes. One board is connected to a PC that acts as a graphical interface to show, online, the network status, the transmitted frames, and the relevant timings.

Figure 3. STMicroelectronics STEVAL-IKR002V5 boards.

During the interactive session the RoboMAC protocol configuration will be shown. Several examples of communications will demonstrate how the protocol works and how it can offer bounded latencies (in the order of hundreds of milliseconds) on COTS low datarate devices. Moreover, several videos of cooperative mobile robot applications will be shown. In the first application two robots (Fig. 4) cooperate to search a radio target that periodically transmits beacons, while in the second application the two robots cooperate in order to maintain the connectivity during the exploration of an area.

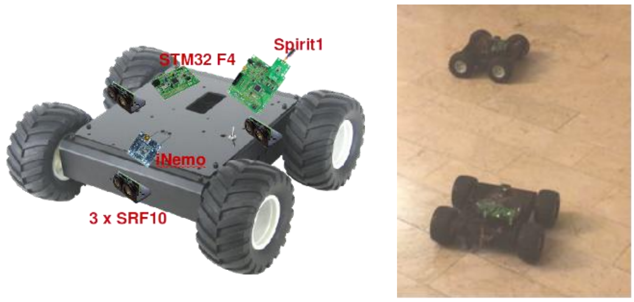

Figure 4. The cooperating robots during an experiment.

Experimental results, in terms of maximum message latencies and packet loss ratio of the two cooperative mobile robot applications will be also presented.

References

[1] G. Patti, G. Muscato, N. Abbate, and L. Lo Bello, "Towards Low-datarate Communications for Cooperative Mobile Robots", IEEE World Conference on Factory Communication Systems (WFCS), Palma de Mallorca, Spain, 27-29 May 2015.

[2] A. Koubaa and J.Ramiro Martínez-de Dios, Eds., Cooperative Robots and Sensor Networks 2015, ser. 604. Springer, 2015.

[3] STMicroelectronics STEVAL-IKR002V5, "SPIRIT1 - low data rate transceiver - 915 MHz - full kit", Apr. 2014, online available: http://www.st.com/st-web-ui/static/active/en/resource/technical/document/data_brief/DM00093462.pdf.