Wireless Access Networks for Raspberry Pi

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Abstract— **Raspberry Pi is currently one of the most interesting platforms for Do-It-Yourself projects regarding signal processing, applications and web/network services. Raspberry Pi is also very well suited for the use during classes for both high school and college courses, thanks for its ease of use, wide availability, excellent support and documentation and low cost. In addition, the availability of support for Raspberry Pi hardware in MATLAB® and Simulink® products by MathWorks, Inc. makes the development of applications for the Raspberry Pi particularly straightforward. Within this context, the proposed demo addresses a field of application not yet widely explored with Raspberry Pi: the deployment of wireless access networks with flexible, user-defined Medium Access Control (MAC) protocols. This result is obtained by adopting a low cost wireless transceiver operating in the ISM band, connected to the Raspberry Pi taking advantage of the Serial Peripheral Interface available on the board, and developing the MAC strategies in MATLAB and Simulink. The demo shows a network of Raspberry Pi boards equipped with the transceiver exchanging data according to TDMA and Random Access MAC protocols, and implementing a distributed video monitoring system, allowing the audience to change physical layer parameters, such as transmission rate and error correction settings and observe their effect on network performance.**

Keywords-Raspberry Pi; Wireless; Medium Access Control.

I. Introduction *(Heading 1)*

The Raspberry Pi platform has gained wide popularity in the last few years thanks to its wide availability, ease of use and excellent support and documentation, combined with its low cost [1] [2]. The Raspberry Pi has proved particularly useful in the development of educational projects, with applications spanning over a wide range of fields [3]. The Raspberry Pi foundation is indeed particularly active in supporting educational and teaching projects involving the use of Raspberry Pi with dedicated resources for teachers and instructors [4].

Several environments to develop applications for Raspberry Pi are available; recently, MathWorks Inc. has made the design and deployment of applications for this platform particularly easy by releasing a Hardware Support Package supporting the Raspberry Pi in its MATLAB and Simulink products [5].

Although Raspberry Pi is currently used in a myriad of learning and academic teaching projects, projects related to MAC design are a notable exception. Projects related to wireless communications using Raspberry Pi are in fact either focusing on layers above MAC and Link layers, by adopting a standard Wi-Fi USB dongle, or on physical layer only, e.g. by proposing hacks to emit FM signals [6].
The proposed demo shows instead how the Raspberry Pi platform can be used to design and evaluate Medium Access Control (MAC) protocols, enabling teachers and students involved in classes dealing with wireless networking to implement a wide set of MAC protocols and studying their performance in the real world. The platform used for this demo is the result of the Wireless Access Networks for Raspberry Pi (WAN4RP) academic educational project carried out at the DIET Department of Sapienza University of Rome [7], supported by MathWorks, Inc. within its Academic Support Program. The rest of this paper is organized as follows. Section II introduces aim and scope of the project, while Section III provides details on the building blocks of the WAN4RP platform developed for the project. Finally, Section IV provides a brief description of the demo.

II. Aim and Scope of the WAN4RP project

The aim of the WAN4RP project is the creation of an experimental framework for the implementation, testing and analysis of Wireless Access principles and procedures. The framework is composed of a network of Raspberry Pi devices equipped with Industrial, Scientific and Medical (ISM) band transceivers. The procedures and protocols to be implemented and tested in the project will explore approaches based on selfish behaviour and competition vs. cooperation and coordination between devices. Protocols based on competition and selfish behaviour will be designed and analysed within the Game Theory theoretical framework. In the case of protocols relying on cooperation and coordination between devices, solutions based on both centralized and distributed Time Division Multiple Access and Frequency Division Multiple Access will be developed. The latter protocols require in most cases the exchange of control information, possibly peer-to-peer; associated procedures will be defined as part of the project.

The project will also address system performance evaluation by introducing software modules dedicated to the collection and analysis of quality indicators (throughput, delay, Packet Error Rate, control communication overhead).

Figure 1. Network device in the WAN4RP demo platform, composed by a Raspberry Pi B+ connected to the RFM73P-S2 transceiver.

The main goals of the project can be listed as follows:

- Realization of autonomous ad-hoc wireless networks of Raspberry Pis using a dedicated low-power ISM band wireless transceiver;
- Implementation of single link performance evaluation tools (eye diagram at the receiver and Symbol Error Probability);
- Implementation of wireless access and networking protocols and procedures, including contention avoidance and resolution, medium access, addressing and multi-hop routing;
- Preparation and release of course material supporting students in the development and experimentation of wireless access protocols and procedures.

The software building blocks required to support the creation of a network of wireless Raspberry Pis were prepared by course instructors, and are made available to students at the beginning of the course, as part of the course material. During the course, students develop, during lab sessions, the software modules implementing the wireless access procedures. Students are organized in competing teams: the competition focuses on the implementation of the most efficient solution given a wireless application scenario; within this context each student is required to perform an individual task, that will be necessary for the implementation of the wireless network. Students of the course are expected to be roughly in a 1-to-1 proportion with the number of network devices, and are thus assigned the task of implementing and testing the algorithms on a specific device.

III. BUILDING BLOCKS

Each network device is formed by a Raspberry Pi Model B+, equipped with a Wi-Fi USB dongle for Wi-Fi access, used as a control interface, and a HopeRF RFM73P-S2 transceiver [8], providing low level wireless connectivity at 2.4 GHz using a Gaussian Frequency Shift Keying (GFSK) modulation, as well as additional features, such as packet handling, Forward Error Correction (with Cyclic Redundancy Check coding) and support for multiple channels / FIFOs. The RFM73P-S2 was selected for three main reasons:

- Relative ease of use and user friendliness
- Low cost (around 5 $ per piece), allowing a network device full cost, including power adapter, Wi-Fi dongle and SD card below 50 $ in December 2014;
- Support for the Serial Peripheral Interface (SPI) interface.

The SPI support by the RFM73P-S2 is particularly interesting, as it guarantees straightforward portability of the software modules implementing MAC protocols and solutions to networks of Raspberry Pis equipped with other transceivers with similar capabilities (e.g., CC2400 / CC2500 transceivers by Texas Instruments [9]). Such porting would in fact require only the realization of low-level functions interacting with the transceiver through the SPI interface.

Development and installation of software modules is being carried out in MATLAB/Simulink, by taking advantage of the Raspberry Pi hardware support packages developed by MathWorks [5].

Figure 1 shows a network device, with a Raspberry Pi B+ connected to a RFM73P-S2 transceiver. The transceiver requires 10 pins to be used out of the 40 available on the Model B+ board. The 10 pins were selected among those between 1 and 26 so to ensure backward compatibility with the Model B board. Complete pin-out description is available on the WAN4RP website.

IV. PROPOSED DEMO

The demo will be composed by 15 network devices that can be organized in one or more networks operating on separate RF channels. The demo will showcase the capabilities of the proposed platform by allowing the networks to transfer data towards a common sink terminal or between pairs of network devices using Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA) -based scheduled MAC protocols vs. random access protocols based on ALOHA and Carrier Sensing Multiple Access (CSMA). The demo will also propose an end-to-end application example of the above access protocols, consisting in a distributed video monitoring system, with Raspberry Pi devices equipped with USB cameras exchanging data over the wireless link and reporting the video feed to a common receiver. In the application example, each camera-equipped Raspberry Pi will periodically capture a screenshot ad send it to a central sink that will receive it and show it on the screen, storing it for offline processing.

The demo will also show how the MATLAB/Simulink hardware support package for Raspberry Pi can be used to develop software for the Raspberry Pi and for devices connected to the Raspberry Pi through the SPI interface.

During the demo the audience will be given the possibility to experiment with the platform by changing configuration parameters on the RFM73 transceiver, in particular transmit data rate at the physical layer and error correction capabilities, and monitoring the corresponding impact on performance, in terms of throughput and quality of the video feed received at the sink.

The demo will be complemented by a poster providing information about the WAN4RP project and its building blocks, and explaining how to download the code to build a replica of the WAN4RP platform.

Although the demo will focus on a stand-alone application, a network formed by Raspberry Pis combined with wireless transceivers would be a perfect fit in a larger network defined on the basis of the Software Defined Networking (SDN) paradigm. The capability of the Raspberry Pi of selecting different MAC protocols on the basis of expected traffic flows, as well as of reconfiguring MAC parameters, such as the slot and frame duration in the TDMA case, fits in fact very well in the goals of a SDN network. In addition, the use of Software Defined Radio (SDR) wireless transceiver, such as a Universal Software Radio Peripheral (USRP) board [10] or a cheaper alternative such as a RTL-SDR USB radio [11], would open the way to full re-configurability of the platform, and in turn of the wireless part of the network. This research line will be the focus of future work, jointly with the definition of an abstract representation of the physical layer and MAC capabilities of the wireless platform, that might be used by the centralized logic of the SDN network to indicate the required performance for the wireless section of the network, to be then translated in a MAC and physical layer configuration by the wireless network controllers.

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