A Radio-frequency Method for Remote Controller Positioning and Device Pairing: Experimental Evaluations

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***Abstract*—In this paper we present a radio-frequency (RF) method for remote controller pointing and device pairing. The method is based on short-range 2.4 GHz radio transmissions over IEEE 802.15.4 network, and a decision-making algorithm that compares radio measurements from multiple devices and decides on the device that the remote controller is pointing at. Experimental evaluations are presented demonstrating effectiveness of the method. Considering the importance of consumer products with remote controllers and multiple devices, the proposed method may provide a viable and cost-effective alternative to the existing conventional solutions.**

I. Introduction

In modern consumer systems multiple devices are controlled by remote controllers. The existing solutions have multiple remote controllers, each assigned to a specific device. Alternatively, a single controller may be assigned to multiple devices, and have explicit device-specific controls (e.g., multiple control buttons uniquely assigned to each device).

Typically consumer devices occupy different locations, and are separated from one another. Those arrangements are suitable for solutions where a remote controller has a single set of controls, and with explicit pointing in the direction of a desired device, determines which device it is targeting, i.e., which device it intends to pair with and control. As an example of the above scenario, in Fig. 1 we depict a system consisting of four ceiling lamps that are installed in one or more adjacent rooms. By pointing at a particular lamp, the remote controller can issue commands (e.g., turning the light on or off, or dimming) using a single set of control buttons. Only the lamp that the remote controller is pointing at should react to the commands, while the other lamps should ignore them.

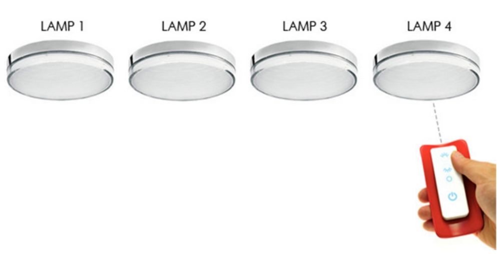

Fig. 1. A system with multiple devices (ceiling lamps) controlled by a single remote controller, with a single set of control buttons.

In the above system the link between the devices and remote controller may be implemented using different technologies. For example, infra-red or sub-visible laser transmissions may be used to convey the commands and decide on which device the remote controller is pointing at. As alternative to those technologies, in this study we investigate application of radio-frequency (RF) transmissions. Due to a broad commercial application and low price, we focused on the 2.4 GHz ISM band and low-power short-range transmissions over IEEE 802.15.4 network.

In this paper an orthogonal polarization method is proposed. There are two antennas at the remote controller side, each transmitting a specific signal. The receiver can differentiate which of the antennas the signal comes from. The receiver measures the received signals' strength (RSSI), and forwards the measurements to the control center, that is in charge of a central decision-making. Subsequently, a unique decision is made on which device the remote controller is pointing at.

II. Formulation of the Problem

In this section we provide details on the orthogonal polarization method. We also explain the decision-making algorithm, i.e., we give an overview of how the system works as a whole, from the moment a user pushes a button on the remote controller, until one of the devices reacts on that command.

A. Orthogonal Polarization Method

In order to transfer maximum energy or power between a transmit (Tx) and a receive (Rx) antenna, both antennas must have the same polarization [1]. When both Tx and Rx antenna are linearly polarized, physical antenna misalignment will result in a polarization mismatch loss ρ. Using the equation (1), the polarization mismatch loss ρ can be determined [2]. Physical antenna misalignment angle is denoted by β ($0° \le \beta \le 90°$).

$$\rho[dB] = -20\log_{10}(\cos\beta) \qquad (1)$$

Two Tx antennas are installed such that their polarizations are mutually orthogonal. When the remote controller is pointing at a device, a relative position of Tx and Rx antennas is presented in Fig. 2. In this case, Tx1 antenna and Rx antenna are identically polarized, while Tx2 antenna and Rx antenna are orthogonally polarized. Accordingly, the device should estimate a large value of the P_{Tx1}/P_{Tx2} ratio. Other devices, which are not in the direction that the remote controller is pointing at, should estimate smaller values of the P_{Tx1}/P_{Tx2} ratio.

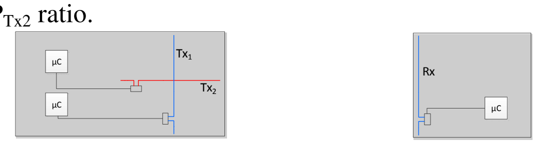

Fig. 2. Antenna arrangement for the orthogonal polarization method (the remote controller is pointing at the device).

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B. Decision-making algorithm

The remote controller, devices and the control center are mutually connected via an IEEE 802.15.4 network.

When the user pushes the control button on the remote controller, a command is sent from the remote controller as a broadcast message.

All devices within the radio range receive the command and estimate the strength of the signals received from the first and the second transmit antenna. The devices then forward the estimated values to a control center.

The control center receives messages from the devices. Subsequently, it extracts and compares the power ratios for each device. Finally, it notifies the target receiver of the action that needs to be undertaken (e.g. should the lamp be turned on, off or dimmed).

We use a centralized decision-making algorithm as depicted in Fig. 3, because it enables us to more conveniently experimentally evaluate the performance of the proposed method. However, the end product should implement an equivalent distributed version of the decision algorithm, thus excluding the control center.

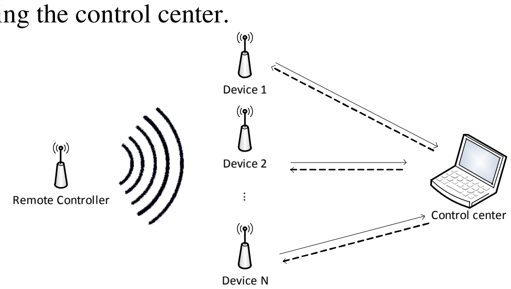

Fig. 3. System level communication in terms of decision-making algorithm. Solid line depicts communication in the direction from devices to the control center. Dashed line depicts the opposite communication direction, in which the control center informs a device of the action that needs to be undertaken.

In indoor environment, a RF wave reflects from many surfaces before reaching a receiver [3]. This effect is known as multipath fading and it affects efficiency of the proposed method. In order to mitigate negative effects of the multipath fading, we apply temporal and frequency diversity techniques [4]. For each packet that originates from the remote controller, we send multiple transmissions in time over five frequency channels and we average the RSSI measurements. This introduces a delay not larger than 500 ms per single command.

III. Experimental Results

We have conducted numerous indoor measurements corresponding to expected real-world deployments.

In a scenario where three devices were installed on the office ceiling, 1.5 m – 4 m apart from the remote controller, we rotated the remote controller in azimuth from -90° to 90°, with the 10° step. The devices were positioned at -70°, 0° and 30°. In Fig. 4, relative power ratio (in decibels) between transmit antenna 1 and 2 is presented. When the remote controller points at one of the three devices, exactly that device measures the highest power ratio. However, one can note that the power ratio becomes even higher when the remote controller points 10°-20° away from the particular device. We explain this as a consequence of multipath propagation, i.e., reflection and diffraction. For -90° to 90°, every device should estimate power ratio values that follow a sine-like curve. We believe that every value deviation from the curve is another consequence of multipath propagation.

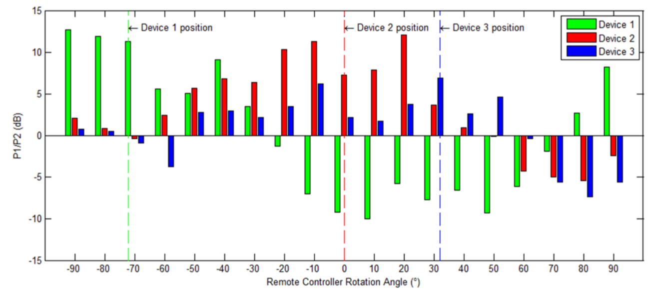

Fig. 4. A scenario with three devices. Received power ratio is showed for every device for every angle of remote controller's rotation. Dashed lines depict actual devices' positions.

Spatial resolution determines the minimal spatial angle between two devices and the remote controller, which the proposed method requires in order to correctly determine the target device. Fig. 5 shows that the minimal spatial angle is around 25°, since for 24°, the second device measures higher power ratio regardless of the remote controller's orientation.

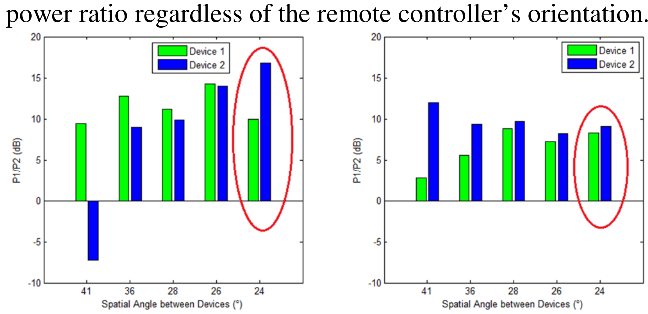

Fig. 5. Spatial resolution. Received power ratio is showed for various spatial angles. The remote controller is pointing at the device 1 (left), and at the device 2 (right). There is a good determination for angles of 41° and 36°, poor but valid determination for 28° and 26°, and no determination for 24°.

IV. Conclusion

We presented an RF method for remote controller pointing and device pairing. The method is based on short-range 2.4 GHz radio transmissions, two orthogonal antennas installed on the remote controller, and a decision-making algorithm, that decides on device that the remote controller is pointing at. For the investigated distribution of the devices in angular domain, the results indicate that the method would lead to correct decisions. Spatial resolution of 25° is determined.

References

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