Poster Abstract: Dual-radio Discovery and Ranging for Infrastructure-less Social Distancing with Janus

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ABSTRACT

Devices to support social distancing must be *energy-efficient* and *accurate*. Bluetooth Low Energy (BLE) meets the first criteria but falls short on the latter. Ultra-wideband (UWB) measures distances with <10 cm error but with relatively high consumption. Therefore, we built Janus, a dual-radio protocol that uses the strengths of each.

CCS CONCEPTS

• **Computer systems organization → Embedded systems**.

KEYWORDS

social distancing, BLE, UWB, discovery, ranging, proximity

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1 MOTIVATION

Social distancing is key to contain viruses such as COVID-19. The Internet of Things can offer tools supporting it across multiple dimensions, e.g., *enforcement* with real-time alerts when a safe distance is crossed, or *monitoring* and *recording* of distances enabling analyses identifying the spread of infection or predictive models.

These ideas have led to a flurry of approaches, many relying on widespread Bluetooth Low Energy (BLE) devices and their ability to estimate distance via signal strength (RSSI). Unfortunately, this technique is known to be grossly inaccurate in practical settings, ultimately yielding unnecessary triggering of alarms and invalidating contact tracing of an individual to infected persons. Our work addresses these issues by complementing the BLE radio with an ultra-wideband (UWB) one, exploiting their relative trade-offs w.r.t. distance estimation (ranging) accuracy and power consumption.

2 JANUS

We call our dual-radio architecture *Janus*—in Roman mythology, a God with two faces. BLE retains the central role of detecting nearby devices (i.e., users) germane to popular approaches. This *continuous* discovery is very expensive in terms of energy, therefore we further reduce the already lower consumption offered by BLE by exploiting our energy-efficient neighbor discovery protocol, BLEnd. The latter, properly adapted, doubles as a means for out-of-band *coordination* of the UWB radios of neighbors, activated only for the time strictly necessary to perform their accurate yet energy-hungry ranging.

Continuous discovery and ranging. BLEnd [2] is a state-of-the-art neighbor discovery protocol developed in our group that offers significant energy savings over typical BLE discovery. BLEnd comes with a companion optimizer to simplify the task of configuring the protocol parameters to guarantee user requirements with predictable performance, considering the schedule structure and the probability of BLE advertisement collisions. For instance, the user can specify that for neighborhoods up to 10 nodes, 95% of the neighbors must be discovered within 10 s, and leave it to the optimizer to output the BLE scan and advertisement intervals that fulfill these goals and minimize power consumption.

Once contact is detected via BLEnd, the next step is to coordinate the UWB ranging across neighbors, to avoid collisions. This is achieved by inserting a *ranging schedule* in the BLEnd advertisement payload, enabling a node to announce *when* its UWB radio will next turn on and *at what offset* from this time it expects to engage in single-sided two-way ranging [1] with a given neighbor. The schedule is dynamically adjusted w.r.t. the neighbors available to minimize the overall radio on time and thus energy consumption.

Implementation. Janus runs atop Contiki on the DWM1001C module by Decawave, combining a DW1000 UWB radio and a Nordic nRF52832 SoC for MCU and BLE. We save additional energy by keeping the UWB radio in deep sleep (~5nA) when inactive, a task complicated by the long delay (~5.5ms) to turn it back on.

The API sharply separates the core functionality of reporting neighbors and their distance from its higher-level use by application, e.g., to define their own notion of contact. Our current "application" simply timestamps and stores in non-volatile memory the neighbor IDs discovered along with the RSSI from the BLE advertisement and UWB distance. On the evaluation boards we use, we can store ~38k of these records. The API also enables applications to set configurations and selectively turn on/off either radio.

3 IN-FIELD EXPERIMENTS

Janus is ready for real-world use, as confirmed by many in-field experimental campaigns with different characteristics and scale. Constrained by space, we focus on two examples illustrating the analysis it enables, followed by a brief account of other experiences.

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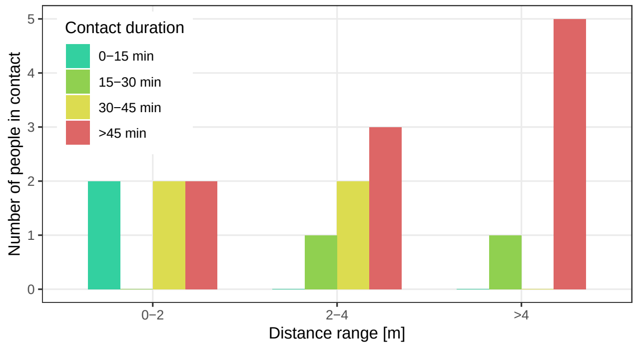

Figure 1: Contact time for one office worker during one day.

Example 1: Office co-workers. We experimented in a typical small-scale setting where the 7 members of a research group are physically colocated in adjacent multi-person offices. Figure 1 shows the cumulative fraction of time one member spent near others in one day. A significant amount of time (>45') was spent very near (<2m) two other members, and only slightly less (30'–45') very near two others. These times are the simple sum of the 15s periods in which Janus detected a neighbor and ranged against it, i.e., they do not necessarily represent a (dangerous) continuous contact. Nevertheless, the chart is indicative of a potentially problematic behavior and is a good example of the type of higher-level analysis enabled by Janus by exploiting accurate UWB distance measurements.

Example 2: Cafeteria. Another campaign investigated scalability, evaluating use in an office cafeteria with ~90 individuals. Nodes on lanyards were handed to workers near the entrance and collected on exit. Figure 2 illustrates the advantage of our dual-radio approach and focuses on a single node, with points denoting a measurement against a neighboring device, distinguished by color. UWB data (top chart) clearly shows three phases: when the node is ready to be handed to the volunteer (*Pre*), when the latter is waiting before being served (*In Line*), and when the volunteer is eating (*Seated*). The relative distance between the node and its neighbors is visible when the volunteer is in line and even easier to discern when seated, showing a nearly constant distance w.r.t. others in the room.

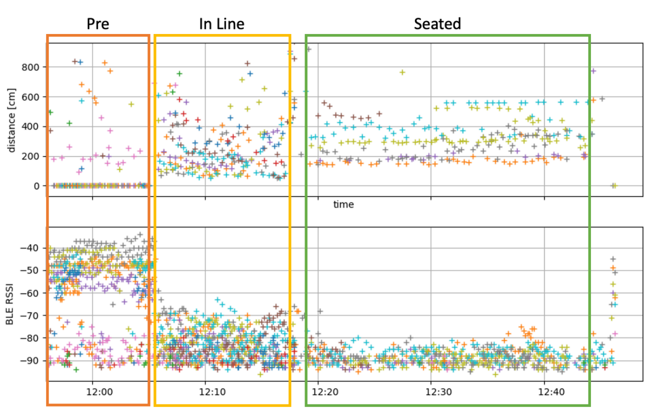

Figure 2: UWB distance and BLE RSSI in a cafeteria setting.

The above confirms that UWB yields rich, fine-grained information from which behaviors can be inferred. The same does not hold for BLE; the trends above are no longer visible in the RSSI of BLE advertisements (bottom chart). The chart reports directly the RSSI value, without any processing or filtering, which could improve the result. Nevertheless, the key point is that the *raw* data returned by UWB (which could be similarly improved by further processing) is *already* extremely accurate and thus useful, unlike the BLE one.

Other Experiences and Summary. We evaluated larger-scale settings by gathering data for 3 days from 87 office workers. Further, we performed a 3-week deployment at two summer camps, with ~50 elementary and middle school children and 14 counselors. The data gathered is precious for camp organizers, as it offers evidence of the effectiveness of the social distancing procedures they established, and paves the way for an application of Janus in schools.

The analysis of over 3 million data points we accrued in total is ongoing. However, these tests have already confirmed the reliability of Janus along with the energy efficiency of its dual-radio approach, enabling multi-month operation. Moreover, the significantly different scale and context of our experiments confirm the *high versatility* of Janus. These desirable properties have been further validated in many industrial trials carried out by companies, discussed next.

4 OUTLOOK

We are collaborating with a multi-national company offering their own social distancing device that, besides the same DWM1001C dual-radio module we used, equips a buzzer enabling real-time alerts and dedicated on-board memory to store contacts, all packaged in a badge-like enclosure. Our firmware, part of the commercial product, has been successfully tested at the premises of several customers, confirming the industry-strength qualities of Janus.

Notably, Janus remains interoperable with mainstream BLE-only approaches, e.g., those by Apple and Google. Indeed, BLEnd changes only the schedule of BLE scans and advertisements, not their nature. Therefore, Janus devices can record BLE advertisements from smartphones and vice versa, although accurate distance estimation is limited to the UWB-enabled Janus devices.

This may actually change soon, as UWB appeared on the latest flagship smartphones by Apple and Samsung. Further, the innovation put forth by Janus is entirely in firmware; it does not rely on hardware-specific features of the two radio chips we used. Therefore, the Janus scheme is directly applicable to existing and upcoming UWB devices, extending the applicability of our solution to the wider user base and use cases enabled by smartphones.

ACKNOWLEDGMENTS

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