Poster Abstract: A Reliable Wireless Nurse Call System: Overview and Pilot Results from a Summer Camp for Teenagers with Duchenne Muscular Dystrophy

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ABSTRACT

We present the design of a reliable nurse call system based on wireless embedded devices and multi-hop protocols. Our work is motivated by the need for such system during annual summer camps for people with muscular dystrophy and the lack of suitable alternative solutions. We describe how our prototype meets the reliability and real-time requirements of such system, and report on results from a two-week deployment during a camp with 13 affected boys in July 2013.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design—*wireless communication*

Keywords

Duchenne muscular dystrophy, nurse call system, Low-Power Wireless Bus, deployment, wireless sensor networks

1. MOTIVATION AND OVERVIEW

Duchenne muscular dystrophy (DMD) is an inherited and progressive muscle wasting disease [1]. It occurs almost exclusively in males—one in 3,600–6,000 live births—and affects primarily skeletal and cardiac muscle. Boys with DMD show first symptoms of muscle weakness of the legs and the pelvis between age 3 and 5. As muscle weakness continues, with the lower half of the body being first affected, most boys become wheelchair-dependent by the age of 13. In their midteens, they lose the ability to feed and care for themselves, and often require assisted ventilation during sleeping hours.

The Muscular Dystrophy Association of Switzerland is a certified non-profit organization providing guidance and support for people with any type of muscle disease and their families. Among other activities, the association organizes annual summer camps for affected people of all ages, mostly boys with DMD. The camps offer social and recreational opportunities, which can have a positive impact on the boys' quality of life and psychosocial well-being, the latter playing a central role in the multi-disciplinary treatment of DMD [1].

Figure 1: Old wired system with control light panel (left) and new TelosB-based system (right).

Challenges. Throughout the summer camps, a nurse call system is required to allow the boys to alert a caregiver of their need for help during the night (*e.g.*, to turn over in bed or to adjust medical equipment, such as breathing mask and leg braces). Unlike medical centers, however, handicapped accessible buildings rarely have a built-in nurse call system. Even if such system exists, handsets and push buttons often need to be adjusted according to each boy's fine motor skills, which is hardly feasible in a closed built-in system.

The caregivers attempted to use wireless baby monitors as a workaround solution, but quickly abandoned them because they compromise privacy and suffer from cross-interference. A custom-built system with 4×4 buttons wired to a control light panel was a better solution (Fig. 1, left). Nevertheless, the system cannot easily handle concurrent alerts, offers no feedback to the boys, and cabling hampers installation. We thus designed a nurse call system based on wireless embedded devices and state-of-the-art protocols, as described next.

Requirements. In discussions with experienced caregivers, we specified five key requirements for our prototype:

1) It should be easy to install, maintain, and extend (*i.e.*, no routing of cables or external power supply at buttons).
2) Through a graphical interface, caregivers should be provided with both visual and acoustic presentation of active alerts, the possibility to confirm alerts individually, and a comprehensive overview of the system and device status.

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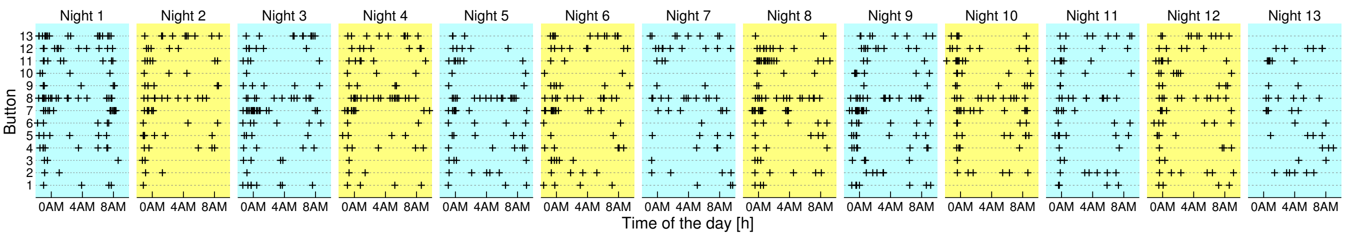

Figure 2: All 1012 alerts against time of day, recorded from 13 buttons deployed at the boys' beds.

3) In particular, the caregivers *must* be informed of failing devices within a few tens of seconds.
4) Alerts triggered through functional devices *must* be presented to the caregivers, ideally within a few seconds.
5) Confirmation of an alert by a caregiver *must* be displayed to the boy as visual feedback within a few seconds.

While the system should be sufficiently low power to operate on batteries for the typical duration of a summer camp (two weeks), energy is not a major concern. Rather, the emphasis lies on *highly reliable and timely bidirectional interactions* between the button devices and the graphical interface.

System design. We built our prototype nurse call system on top of the Low-Power Wireless Bus (LWB) [2]. LWB suits our needs, because it provides reliable and energy-efficient multi-hop communication; supports one-to-many and many-to-one traffic, which we exploit for bidirectional interactions; and allows for rapid and reliable detection of failing devices.

Specifically, we connected custom-built push buttons via three meter long cables to the expansion connectors of TelosB nodes, called *sources* (see Fig. 1, right). A dedicated TelosB, acting as sink and LWB *host*, is connected to a laptop, which displays the graphical interface according to 2) above.

To satisfy 4) and 5) at low radio duty cycles, we set the round period in LWB to four seconds. All sources generate a status message with the same period, reporting whether a button was pressed. Thus, in our specific setting, all sources get the chance to inform the host of possible alerts, and the host can inform them of alert confirmations by piggybacking onto the schedules it sends, within at most four seconds respectively. To satisfy 3), the host flags a source as failing if it misses ten consecutive status messages from this source [2].

We use the on-board LEDs of a source to provide visual feedback on the alert status to the boys. Normally, all LEDs are off. The red LED means that the button was just pressed and an alert will be sent to the host. The host acknowledges the reception of the alert in the very next schedule it sends. Upon receiving the acknowledgment, the source turns on the blue LED. At this point, usually within four seconds, the boy knows that his alert was successfully received and is being displayed in the graphical interface. Once the caregiver confirms the alert, the host embeds this into the next schedule and the boy will observe the green LED. Finally, the caregiver clears the green LED by pressing the button at the boy's bed. To ensure highly reliable end-to-end interactions, we resent alert notifications, acknowledgments, and confirmations until eventual delivery, and use CRC checks and careful parsing against corrupted data.

2. DEPLOYMENT AND PILOT RESULTS

We deployed our prototype for two weeks during a camp in July 2013. There were 13 boys with DMD of age 11 to 18, and 21 caregivers. We installed 22 TelosB devices across several rooms and a hallway in a 20×10 meters one-story building: 13 with buttons at the beds, 1 with a button in the bathroom, 7 relays, and 1 sink/host attached to a laptop.

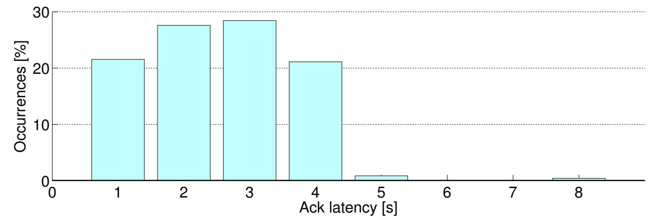

Figure 3: Distribution of ack latency from 9 sources.

Besides some minor issues with detached buttons, the system operated smoothly for the entire duration of the summer camp. The boys were particularly pleased with the visual feedback on the alert status, and the caregivers appreciated the timely and comprehensive graphical interface. The caregivers agreed that the new system is a big improvement over the old wired system, in terms of usability and reliability.

We recorded 1012 alerts throughout the camp. Fig. 1 plots alerts per button against time for the 13 consecutive nights. We see that most alerts are in the beginning of the night while the boys fall asleep, and that some of the boys require more care than others. For example, the boy using button 8 wears a breathing mask, which needs frequent adjustments. Looking at individual buttons, we also notice a certain alert frequency and pattern that repeat across the different nights.

As a preliminary analysis of system performance, we plot in Fig. 2 for nine sources the distribution of *ack latency*, the time from when a button is pressed until the reception of the acknowledgment from the host. We see that nearly all alerts are acknowledged within 4 seconds, which is expected since the periods of LWB rounds and status messages are set to 4 seconds. The few outliers are because almost (but not) all messages are received at the first try: the average reliability is 99.95% and the average radio duty cycle is 3.94%.

3. ONGOING WORK

Since the boys in their mid-to-late teens start to have difficulties in pressing the push button, we are already working on a voice-activated solution that triggers an alert when a specific word is detected and live streams voice signals for some time to help diagnose the problem. This raises several challenges related to the hardware/software architecture and real-time communication under high bandwidth utilization.

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4. REFERENCES

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