Wearable Sensor Networks for Measuring Face-to-Face Contact Patterns in Healthcare Settings

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Abstract. We describe the experimental deployment of a network of wearable sensors that allows the tracking of the location and mutual proximity of individuals in a hospital ward, in real time and at a large scale. In the course of the deployment, all individuals accessing the premises were monitored for a period of one week, including health care personnel, patients, visitors and tutors. The data collected yields a rich dynamical picture of the contact patterns between individuals and between categories of individuals. As an example, here we show that by constructing a cumulative weighted contact network aggregating the dynamical data on the entire duration of the deployment, it is possible to reliably uncover persistent relations among individuals.

Keywords: infectious diseases, RFID, wearable sensors, mixing patterns.

1 Introduction

The control of hospital-acquired infections and the development of appropriate strategies to reduce their human impact and related economic burden are currently major public health priorities. Reaching these objectives is however hampered by the limited empirical knowledge available to identify the key factors responsible for shaping the spreading behavior of such infections in the hospital community. While the pattern of contacts between individuals is known to play a crucial role in the spreading of infectious diseases [1], experimental information has been critically lacking. Empirical studies have been conducted to determine the patterns of contacts between and within groups and in different social settings [2], however, insufficient knowledge is currently available about the pattern of contacts in a healthcare settings.

Recent technological advances have paved the way to mining real-world person-to-person interactions by means of mobile devices and wearable sensors. Bluetooth and WiFi technologies give access to proximity patterns [3,4,5], and even

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face-to-face presence can be resolved with high spatial and temporal resolution [6,7,8,9]. Thus, a new field of data-driven investigation is opening up, focused on exploring the interplay of the network dynamics with the dynamical processes, such as the spread of an infectious agent, that take place on these networks [10,11].

Here, we describe an experimental data collection that took place in November 2009 in a pediatric ward of the Bambino Gesù Hospital in Rome, involving several hundred participants for a period of over one week. Section 2 describes the technology we deployed, Section 3 shows how the data we collected expose some simple contact patterns, and Section 4 discusses the broad scientific and practical implications of these new capabilities.

2 Sensing Face-to-Face Proximity

The data collection infrastructure we used was developed by the SocioPatterns project [12] and is based on active Radio Frequency Identification Devices (RFID) embedded badges that participants in the study wear on the chest. RFID devices exchange ultra-low power radio packets in a peer-to-peer fashion, as described in Ref. [7,8,9]. Exchange of radio packets between badges is only possible when two persons are at close range ($\sim 1 - 1.5$m) and facing each other, as the human body acts as a shield for the radio frequency used to communication. When a relation of face-to-face proximity (or "contact", as we will refer to it in the following) is detected, the badges report this information to radio receivers installed in the hospital ward, and this information is then processed by a central computer system.

The RFID tags were hermetically sealed in plastic bags and attached to the participants' clothing. All tags have a unique identification number which is used to link individuals with the corresponding personal information. The study was approved by the Ethical Committee of the Bambino Gesù Hospital. Health personnel, patients, tutors and visitors who accessed the monitored pediatric ward were invited to participate in the study and to sign an informed consent. All participants were given an RFID badge and asked to wear it at all times.

3 Cumulative Contact Networks

As an illustration of the capabilities of the methodology described above, we show two interaction pictures gleamed from the contact data by aggregating them over the course of the deployment. Given two individuals i and j, the system measures the total amount of time w_{ij} that those individuals spent in face-to-face proximity, i.e., the system builds a weighted cumulative contact network among individuals. On focusing exclusively on patients and their tutors, and retaining only the strong connections with $w_{ij} > w_0$, where the threshold $w_0 = 5$min, we build the contact graph of Fig. 1. We see that the most frequently observed pattern consists of a patient linked to the corresponding tutor. A few isolated individuals are visible at the bottom, and a few more complex structures are the

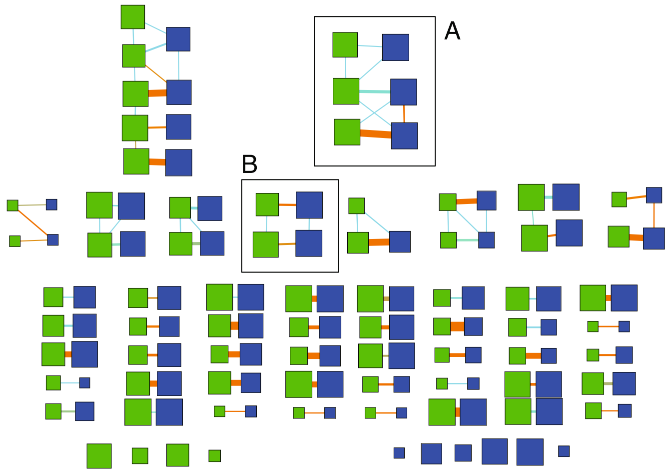

Fig. 1. Cumulative contact network of patients (blue) and tutors (green). Nodes represent unique individuals, and edges between nodes represent a cumulative face-to-face time in excess of 5 minutes, over the monitoring period. Node size increases with the on-site presence of the corresponding individual, and edge thickness increases with the cumulative face-to-face time. Orange edges correspond to contacts that are stable over time, while cyan edges indicate intermittent connections. Few patient nodes are isolated because the corresponding tutor declined participation in the study, or did not wear the RFID tag correctly.

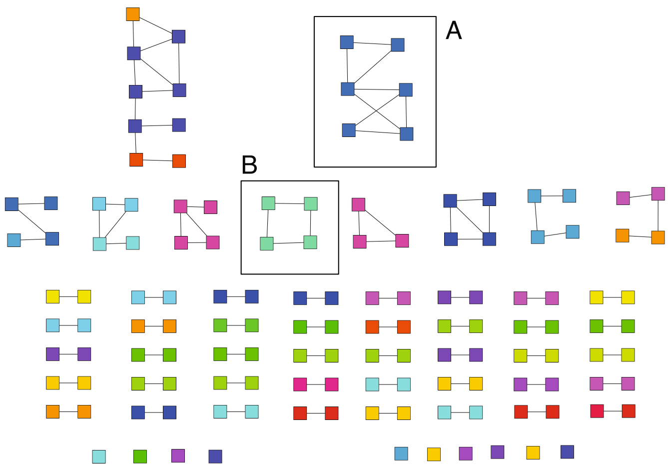

Fig. 2. The cumulative contact network of patients and tutors. The network layout is identical to that of Fig. 1, but here the nodes are colored according to the room the corresponding individual was assigned to, based on the hospital records.

top. Box B, for instance, shows two patient-tutor pairs sharing a hospital room, as visible from the corresponding Box in Fig. 2. Contacts between each patient and the corresponding tutor in Box B are strong and stable, while contacts across the two pairs are weaker and intermittent. In the case of Box A, a patient-tutor pair (the central one) used the room for the entire duration of the deployment, while the other two pairs (top and bottom pairs) spent subsequent and non-overlapping time intervals in the same room.

4 Perspectives

The experimental approach presented here, based on peer-to-peer RFID devices, offers an innovative solution to the collection and investigation of the patterns of contacts among individuals in a large hospital setting in a non-obtrusive way. This approach allows measuring critical parameters to estimate the likelihood and the expected pattern of infection transmission from person to person in a specific setting. The integration of RFID technology with traditional approaches for prevention of nosocomial infections may help identifying critical patterns that deserve tailored interventions and implementing efficacious prevention strategies.

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