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Gravity gradient routing for information delivery in fog Wireless Sensor Networks

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ABSTRACT

Fog Computing is a new paradigm that has been proposed by CISCO to take full advantage of the ever growing computational capacity of the near-user or edge devices (e.g., wireless gateways and sensors). The paradigm proposes an architecture that enables the devices to host functionality of various user-centric services. While the prospects of Fog Computing promise numerous advantages, development of Fog Services remains under-investigated. This article considers an opportunity of Fog implementation for Alert Services on top of Wireless Sensor Network (WSN) technology. In particular, we focus on targeted WSN-alert delivery based on spontaneous interaction between a WSN and hand-held devices of its users. For the alert delivery, we propose a Gravity Routing concept that prioritizes the areas of high user-presence within the network. Based on the concept, we develop a routing protocol, namely the Gradient Gravity Routing (GGR) that combines targeted delivery and resilience to potential sensor-load heterogeneity within the network. The protocol has been compared against a set of state-of-the-art solutions via a series of simulations. The evaluation has shown the ability of GGR to match the performance of the compared solutions in terms of alert delivery ratio, while minimizing the overall energy consumption of the network.

1. Introduction

Popularity of Wireless Sensor Networks (WSNs) has been constantly increasing over the past number of years. Nowadays, WSNs could be found in most of the modern indoor and outdoor locations, where WSNs support a wide variety of applications. It is expected that this growth will continue, and, in the near future, multipurpose WSNs will be deployed everywhere. To sustain this, performance improvements will be required at all layers of WSN architecture, including the design of wireless sensor devices, their communications and applications. Although the capacity of a modern WSN today allows for certain complex tasks (e.g., data fusion), the improvements will continue to increase computational power of the WSNs, their efficiency and autonomy of operation. To take full advantage of the increase, CISCO have recently proposed the concept of Fog Computing [1], where services are proposed to be hosted (at least partially) by near-user devices (e.g., wireless sensors, gateways). The concept offers a number of advantages, including increased reaction time, sustainability and user-awareness. However, for the concept to be accepted by the general population, a critical mass of Fog Services need to be rolled-out. In this article we consider a possible Fog implementation of WSN Alert Services.

Typically, operation of a WSN does not imply direct interaction with the user. Monitoring data collected by the network is forwarded via a set of dedicated getaways to a cloud. On the cloud the data are processed and analyzed by an appropriate service that, if required, alerts the user. For example, based on results of WSN monitoring, asthmatics patients may be alerted of dangerously high pollen and pollution levels. However, transmitting information from sensors to the cloud requires additional resources (e.g., continuous Internet connectivity) lack of which may potentially delay alerting the user. As an alternative, certain analysis of the monitoring data can be carried out by the wireless sensors, while alerts detected as a result of the analysis can be handed-off to the user's hand-held devices (e.g., smart phones) directly by the sensor nodes. In this way, alerts will be delivered to the users spontaneously (i.e., on occurrence). This creates an opportunity for a WSN-based Fog implementation of Alert Services.

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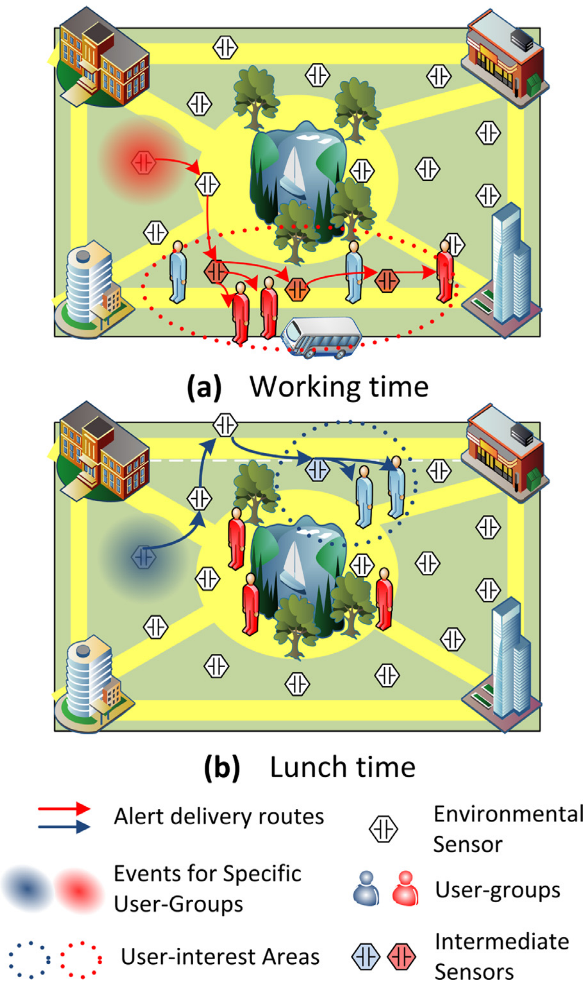

Fig. 1. Fog implementation of a WSN Alert Service: Application scenario. The alert delivery changes following the change in user-presence within the environment. The change can be seen between (a) working time, and (b) lunch time. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

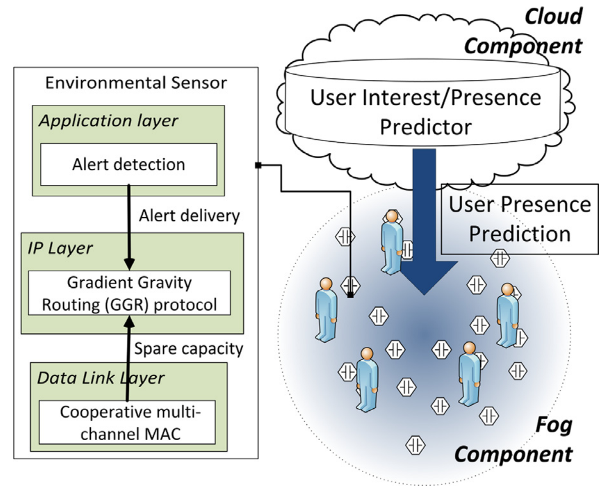

Fig. 2. Overall cross-layer architecture of the proposed user-group aware Sensor.

In this article we focus on a particular application scenario, illustrated in Fig. 1. The scenario includes a dense multi-purpose WSN, the *Sensor Environment* (*SE*). Each sensor is allocated a monitoring task and generates alerts on occurrence of specific events. Alerts are delivered to the users with regards to their preferences in order to avoid potential loss of user-interest. Based on the similarity of preferences the users are organized into groups, and group-based presence of the users is used to guide the alert delivery process. Thus, an alert, generated within the environment is initially delivered to a sub-set of intermediate sensor-nodes, located in vicinity of users from appropriate groups. Selection of these nodes will vary depending on the type of the alert (blue or red on Fig. 1) and time of its generation (lunch or working time). Once received by the intermediate nodes, the alert is handed-off to the devices of the users themselves. Depending on user presence, any sensor may become an intermediate node and act as a gateway for the users. In other words, a user's device that comes into close range of a sensor will receive spontaneous alerts from the WSN. We consider events that may engage simultaneously a number of sensors, which will generate similar alarms. Such alarms will be detected and fused together by the SE in order to achieve greater usability.

For the considered application scenario, achieving maximal performance efficiency will require solving a number of multi-disciplinary problems, such as: (I) gaining a deep understanding of user-groups and their mobility pattern, (II) developing efficient mechanisms of alert-detection, (III) optimizing alert delivery within the SE, and finally, (IV) developing alert fusion and hand-off to the users. Some of the problems have already been considered in other research. For example, user-group formation and mobility (Task (I)) is commonly considered by Social Network Analysis (e.g. [2–4]). Edge Mining [5] has been proposed for sensor alert detection (Task (II)). In this article, alert delivery within the SE (Task (III)) presents the focal point, where the main contributions include:

- Gravity Concept for user-group aware delivery of alert-based information in an SE. The concept takes into account group mobility of the users of the SE. The delivery prioritizes areas of the SE with higher user-presence, and is carried out in a fully distributed fashion that supports alert fusion.
- A user-group aware multicast routing protocol, namely the *Gradient Gravity Routing* (*GGR*) protocol is proposed. The protocol is based on the Gravity Concept and insures resilience to potential sensor-load heterogeneity across the SE (e.g., due to user-to-user traffic).
- Extensive simulation work that combines both real and synthetics traces of user mobility. The evaluation through the simulations compares the multicast routing protocols with well known protocols, as well as analyses the energy utilization of the sensor devices, average delivery ratio, forwarding rate, as well as the average delay.

The remainder of the paper is organized as follows: Section 2 present our vision of the Fog WSN Alert Service's architecture. Sections 3 and 5 describe in detail the Gravity Concept, the GGR solution and its validation. Section 6 provides an overview of the related work, and lastly Section 7 concludes the paper.

2. Alert service architecture

Despite the improvement in the design of wireless sensors, their capability remains insufficient for some of the tasks (e.g., user group analysis) identified earlier. To accommodate such tasks the SE architecture (Fig. 2) incorporates a dedicated cloud component. However, compared to the conventional design, responsibilities of