Context awareness and information processing in opportunistic ubiquitous systems

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ABSTRACT

The prevailing assumption in most context-aware ubiquitous computing systems is that of a constantly available stream of sensor data or of events. From these, the relevant context is infered using signal processing, machine learning, or higher-level reasoning approaches. Opportunistic sensing is seen as a way to gather information about the physical world in the absence of a stable and permanent networking infrastructure. Such situations occur in emergency/disaster situations when centralized infrastructure is not available, in transport scenarios where only limited local neighborhood connectivity can be assumed, in participatory sensing, in the spread of information in social networks. Essentially these characteristics occur in ambient ecologies characterized by a high level of mobility, operating over long periods of time in dynamic and open-ended environments. Coping with the disconnected nature of the underlying physical layer calls for new networking paradigms. Context recognition methods must however also be rethought to cope and eventually to take advantage of the nature of opportunistic sensing. The aim of this workshop is to take a snapshot of the state of the art in opportunistic sensing; to sketch the ubicomp application areas where opportunistic sensing is becoming of increasing relevance, and to outline the challenges and new approaches to infer contextual information from opportunistically sensed data.

BACKGROUND

Considering the huge amount, and ever growing number of a vast manifold of heterogeneous, small, embedded or mobile devices shaping the ubiquitous computing landscape, makes traditional design-time-defined sensing approaches more and more incompatible. Ubiquitous computing system designs will have to and are already successfully attempting to revert the principle of design-time-defined sensing, to one where technology in a self-aware approach attempts to opportunistically collect data from whatever sources (physical sensors, data repositories, referenced data in the internet) and try to make meaning out of it. Observably, large scale ubiquitous computing systems are undergoing such a paradigm shift already today, a prominent example being positioning systems implemented in the current generation of smart phones, opportunistically making use of GPS, GSM cell, WLAN and BT signals to position the device depending on their availability.

As such, opportunistic sensing and information processsing appears as a fundamental principle underpinning self-aware ubiquitous computing systems involving very large numbers of entities in open ended environments, and it is a key towards of future generation ubicomp systems [3]. Thus, opportunistic sensing and information processing is not limited to a specific application domain, but rather it observably represents a paradigm shift in large-scale self-aware systems. Thus, "application domains" span from sensing policies for open ended systems, to system able to meaningfully integrate everything that "emerges" out of technological progress, but cannot be foreseen - and thus not be designed for (at design time).

OPPORTUNISTIC SENSING

Until recently sensing networks consisted of homogeneous clusters of small sensor nodes, communicating wirelessly, executing a fixed set of applications in a distributed fashion. These wireless sensor networks are the interface between the cyber world and the physical world, where data is streamed over, what is assumed to be, a simultaneous end-to-end path from source to destination. This however is in contradiction with what actually happens in mobile networks. Nodes move around while changing associations with their environment constantly because there is no stable infrastructure [19]. This is recognized in the increased interest in delay tolerant, or opportunistic networks [9] [11] [16]. No fixed infrastructure is assumed and simultaneous end-to-end communication paths do rarely exist. Instead, mobile nodes, known as mules or ferries, carry data from cluster to cluster. Sensor data is collected on the way and is disseminated in an opportunistic fashion [12]. This idea can be taken one step further. Crowd sourcing or urban sensing uses mobile phones as input devices in addition to existing infrastructures and depends on people's mobility. A traditional device-centric approach becomes a human-centric approach [1] [10] [2] [20]. A mobile phone user not only becomes a collector

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of data, she also filters and disseminates data and will act on data she receives, knowingly or not. Depending on a user's needs, opportunistic alliances with other users sharing the same context will be made to do the necessary sensing, processing and actuation. Personal data is mixed with local and global data, resulting in an enormous amount of information. One of the great challenges in opportunistic sensing is narrowing down this information into chunks that are useful for the users. Which data will be collected and how much? How is the data disseminated and routed through the network? How do we decide on a common context? How can we use opportunistic sensing in new and innovative applications [4] [7] [14]?

Context recognition in the classical sense

Context awareness is the underpinning of adaptive user centric ubiquitous computing system [6]. Assuming a networking infrastructure delivering sensor data one common approach to context recognition is to use machine learning techniques to classify a set of sensor data into the relevant output classes. The context recognition chain is the set of processing steps used to infer the context from the sensor data. The methods in the chain are not codified. Various methods may be used, but one common processing structure consists of: data acquisition from the sensors; segmentation of the data stream into sections of interest likely to contain an activity; feature extraction within these section to reduce their dimensionality; classification of the features into a set of output classes (activities); and "null-class" rejection.

Challenges of opportunistic context awareness

The classical context recognition chain assumes a design-time definition of the *input space*, that remains constant throughout use. By input space, we mean the number of sensors, their position, modality, sample rate, latency, as well as their physical sensing characteristics. These assumptions are not guaranteeed from an opportunistic sensing perspective. Thus they must be relaxed, and new sets of processing strategies must be defined. Essentially, this calls for:

- New sensing and networking principles, with aspects such as compressive sampling, in-network processing, and delay tolerant networks becoming of increasing relevance
- Context processing architectures and frameworks that allows for a spontaneous emergence of goal-directed sensing networks
- Signal processing and machine learning techniques that cope and capitalize on the new nature of opportunistic sensing. Aspects such as dynamic channel selection and weighting, ensemble classifiers and quality of context become more relevant to select and combine the appropriate sources of informations at run-time to reach an application defined performance goal.
- Eventually, new forms of ubiquitous computing applications are enabled by opportunistic sensing, with prominent examples being urban sensing, crowd-sourcing, and opportunistic activity recognition. All of these attempt at achieving a reliable context awareness goal from intermitently available and opportunistically discovered resources. Beyond this, essentially these applications attempt at higher robustness despite lack of control on the quality of the source data, thereby addressing fundamental aspects of real-world deployment of complex ubiquitous systems.

We indicate below how a few ubiquitous computing application domains that capitalize upon opportunistic sensing.

Mobile crowd sensing

Understanding in real-time crowd dynamics has great potential to raise the global awareness of first responders during emergency situations and rescue operations. The widespread availability of mobile sensor-enabled devices calls for new methods making a decentralized use of sensor data to infer key building blocks of crowd behavior [24]. From an emergency scenario perspective, the availability of central infrastructure cannot be assumed and an application must resort to decentralized participatory sensing. Nevertheless, through repeated interactions with members of a crowd and identification of pairwise correlations between sensor data a global picture about the crowd structure may be inferred [23]. The underlying challenge amounts to a combination of opportunistic sensing and information spread in the crowd, and information processing.

Urban Sensing

Mobile phones, vehicle-mounted sensors and infrastructure in urban environments combined with publicly available information, like weather, train and bus schedules or traffic, enable users to sense, record and share their personal environment. This gives rise to new and innovative applications, e.g. social networking, traffic management and car guidance systems, or mapping environmental parameters, like air pollution.

Activity recognition in opportunistic sensor configurations

Recognizing human activities and gestures [5] is important in fields such as pervasive computing [22], wearable computing [13] and in human computer interaction (HCI) [15]. It enables systems capable of pro-actively supporting users with just-in-time assistance, systems responding to natural interactions, or systems mining daily life patterns. A few applications include gestural mobile interfaces [8], industrial worker's assistance [21], or healthcare [17]. In mobile use, activity recognition consists in inferring the user's activities from the data of a set of sensors placed on the body. Current approaches usually require a specific deployed infrastructure for a specific recognition task. This is not desireable for a widespread use of context-aware systems. Users are at times in highly instrumented environments and at other times in places with little sensor infrastructure. Users carry various sensor enabled devices, such as mobile phones, watches, or smart garments. As the user leaves devices behind, picks up new ones and changes his outfit, the type and location of on-body sensors varies, and the sensing environment changes. Besides, in highly challenging situations data loss are not unexpected. Sensor may slip, degrade, or fail. Power saving may call for reduced sample rate, or use of lower computational complexity algorithms to save power at the expense of reduced accuracy. Thus, a more flexible *opportunistic* approach to activity and context recognition is desired [18].

Smart Appliances and Companions
Digitally enabled devices acting in spontaneous wireless ensemble configurations, able to adapt to changing service requirements and situations (like positioning of mobile phones, cooperative wearables, implicit wearable to infrastructure interaction)

Traffic, Transportation and Logistics
Collective vehicular settings (car crowds) and self-aware goods, acting and requesting services while in transit through changing assistance infrastructures (e.g. Web of Things).

Human Assistive Technologies in Extreme Situations
Service architectures and their autonomous, self managing service provision to humans with specific goals (e.g. wayfinding, guidance), in extreme situations (e.g. rescue, evacuation) where the setup of available instrastructure cannot be foreseen at design-time and is likely to change over time.

OUTCOMES

Opportunistic sensing not only calls for new networking paradigms, but also for new means to infer meaning from aquired sensor data. As a result of surveying the domains where opportunistic sensing enables new forms of applications and the approaches used in these domains, we will be able to paint a clear picture of the set of algorithms, methodologies and tools that are currently proposed. From this we expect cross-fertilization accross the application domains, with methods pioneered in one domain being translated to other domains. As a result we seek an overall information processing architecture to infer context from opportunistically sensed data. However, other outcomes include a documented set of lesson's learned and best practices to design opportunistic context-aware systems. Also, we expect to identify the new research directions in the methodologies (sensing, networking, machine learning, signal processing, and reasoning), as the emerging application domains for opportunistic context awareness.

The papers submitted to this workshop are published in the adjunct proceedings to the conference. A concise version for publication in a jointly authored article is also possible.

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