Opportunistic IoT: Exploring the Social Side of the Internet of Things

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***Abstract*—The Internet of Things (IoT) is a technical revolution that represents the future of computing and communications. Under its vision, the next-generation Internet will promote the harmonious interaction between human, society, and smart things. The current research in IoT is mainly from the perspective of connecting and managing things. The humanized, social side of IoT, however, is still not explored. In this article, we intend to present the IoT from the human-centric perspective. By analyzing the tight-coupled relationship between human and opportunistic connection of smart things (e.g., mobile phones, vehicles), we propose *Opportunistic IoT*. It enables information sharing and dissemination within/among opportunistic communities that are formed with the movement and opportunistic contact nature of human. We characterize the bi-directional effect between human and opportunistic IoT, present the innovative application areas, and discuss the challenges raised by this new computing paradigm.**

Keywords- Internet of things, human-IoT Interaction, social IoT, opportunistic networks, social interaction

I. INTRODUCTION

The Internet of Things (IoT) refers to the emerging trend of augmenting physical objects and devices with sensing, computing, and communication capabilities, connecting them to form a network and making use of the collective effect of networked objects. It is a technical revolution that represents the future of computing and communications [1].

Under to the vision of IoT, the next-generation Internet will promote *the harmonious interaction between human, societies, and smart things* [2]. In the past few years, significant research efforts have been made on IoT, mainly from the *thing-oriented* perspective. A wide range of areas is covered, including object identification and tracking, object networking/addressing, sensing data visualization/access, object control, and so on [3]. Nevertheless, the "harmonious" interaction between human and IoT, or in other words — **the social side of the IoT**, has yet little been explored.

The traditional view of IoT attempts to connect all the physical objects to build a global, infrastructure-supported IoT. In this position paper, however, we will present **opportunistic IoT,** which addresses *information/resource sharing within and among opportunistic communities (with pairs of devices) that are formed based on the movement and opportunistic contact nature of human*. Various personal devices, such as mobile phones, wearable devices, vehicles, can form opportunistic IoT when they are equipped with the short-range radio and sensing modules. We illustrate the concept of opportunistic IoT through the following "opportunistic trading" use case.

Opportunistic trading, differs from traditional market-based trading and online shopping, is founded on the disseminating and matching of trading requests in opportunistic IoT environments. For example, Bob has a "Harry Potter" book; he has read it and wants to sell it via the opportunistic trading agent (OTA) running on his mobile phone. While Bob moves each day, his trading request is shared by the people in the vicinity (forming an opportunistic community of mobile phones). Since the moving range and mobility pattern of Bob is roughly fixed (and thus the people he can encounter is limited), to increase the number of trading request receivers and speed up the request dissemination process, OTA will employ other mobile nodes as "brokers" to help store and forward Bob's trading request. How to select brokers become a significant yet difficult problem, where we should consider about the popularity of the node (in terms of its contact patterns) and other social features (e.g., willingness to act as the broker). Two days later, Alice, who lives in another district of the city, is found by OTA and the selected brokers after trading-request dissemination and matching. The opportunistic trading, comparing with existing trading modes, has the unique features such as: pervasiveness, delay-tolerable, social connection, and opportunistic.

The above scenario demonstrates the bi-directional relationship between human and opportunistic IoT. On one hand, opportunistic IoT becomes the primary media to sense and monitor human behaviours (e.g., mobility patterns can be learned from the GPS trajectories collected from user carried mobile phones); on the other hand, the work performance of IoT is also affected by human behaviours (e.g., social features are important for broker selection). In summary, opportunistic IoT presents a promising research domain to study the social side of the IoT. In the following sections, we first elaborate the bi-directional effects between human, societies and IoT; the potential application areas and challenges of opportunistic IoT will then be described; we finally conclude the paper and present the future work.

II. THE BI-DIRECTIONAL EFFECTS BETWEEN HUMAN AND IOT

By analyzing the tight-coupled relationship between human and opportunistic connection of smart things, we present the bi-directional effect between human/societies and opportunistic IoT, as shown in Fig.1.

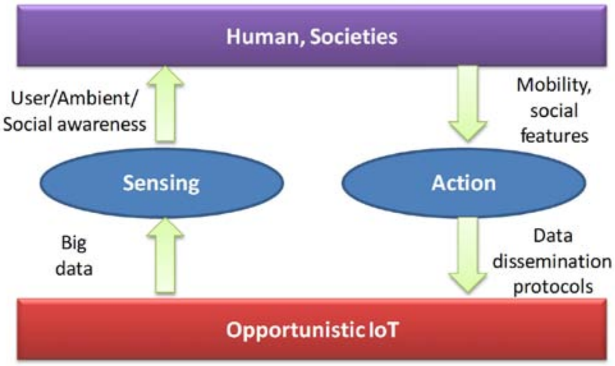

Figure 1. The bi-directional effects between human, societies and IoT.

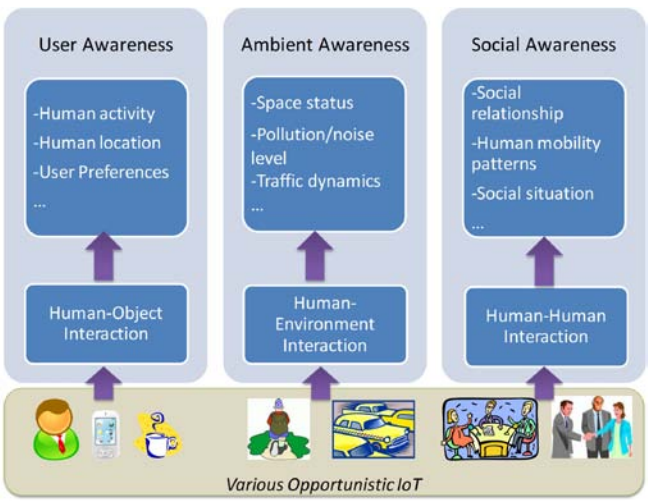

Figure 2. Human-Centric Sensing with Opportunistic IoT

A. *Human-Centric Sensing with Opportunistic IoT*

As illustrated in Fig. 2, various IoT devices (equipped with sensing and short-range communication capabilities) are weaved deeply into the fabric of human daily life. The diverse features of these devices present unprecedented opportunities to understand the aspects of interaction between humans and real-world entities. We characterize these human-centric interactions as *human-object*, *human-environment*, and *human-human* interactions. By analyzing the collected interaction data with advanced machine learning and data mining techniques, the opportunistic IoT is endowed with three sensing capabilities: *user awareness*, *ambient awareness*, and *social awareness*. We characterize the attributes of them as follows.

- *User awareness* refers to the ability to understand personal contexts and behavioral patterns. Examples include human location, human activity, user preferences, and so on.
- *Ambient awareness* concerns status information on a particular space. Examples include space status (crowded or empty), pollution/noise level, and traffic dynamics (e.g., traffic jams).
- *Social awareness* goes beyond personal contexts and extends to group and community levels. The objective is to reveal social interaction (e.g., group detection, friendship prediction, situation reasoning) patterns, human mobility patterns, social situation (in a meeting, at a restaurant, meeting friends), and so on.

B. *The Effect of Human Behaviors to Opportunistic IoT*

Data sharing is the major application area of opportunistic IoT. Since the source node and destination nodes might be unaware of each other (e.g., in the opportunistic trading use case, *Bob* and *Alice* are unaware of each other) and may never meet in opportunistic networks, forwarding a message (e.g., selling a book called "Harry Potter") from its sender to the nodes of interest (e.g., from *Bob* to *Alice*) becomes a big challenge. A trivial solution would be to flood the whole network with the message [4], but this would clearly saturate both network resources (in terms of available bandwidth) and device resources (e.g., in terms of energy, storage, and so on).

A better solution is to replicate the content to only selected nodes that have more chances to contact and influence others, and thus the *broker-based* solution is proposed (as demonstrated in the opportunistic trading use case). With this solution, each node (e.g., node *Bob*) carrying a message evaluates the suitability of any other node it makes contacts with as the broker (many social features are measured, as depicted later). Messages are thus *opportunistically* disseminated by exploiting both the source node (e.g., node *Bob*) and the selected brokers, until they reach a node of interest (i.e., node *Alice* who lives in another district of the city wants to buy the book).

In opportunistic IoT, contacts between nodes are fundamentally tied with users' social behaviors (e.g., two mobile phones contact when user *A* and *B* meet in a coffee shop). We thus need to exploit various social behaviors in designing broker-based data dissemination protocols. For example, when selecting brokers, the social features such as user popularity (does the broker meet many different people each day), social willingness (is the broker willing to carry and forward the message), social network structure (Bob's friends are more likely to act as his brokers), preferences (the broker may filter dissemination it tasks according to his/her preferences), and so on, will affect the performance of the protocol designed. Therefore, we state that the application of opportunistic IoT is also driven by exploring human behaviors and social features. One use case is illustrated in Fig. 3, where a broker is selected to carry and forward a message in the school campus, by measuring her social features such as social popularity and willingness.

Overall, the bi-directional effects between human, societies and IoT reflect the basic nature of opportunistic IoT. It also reveals the social side (while not technical side) of the IoT and presents a human-centric (while not thing-oriented) view of IoT, which has been little concerned in previous studies of IoT.

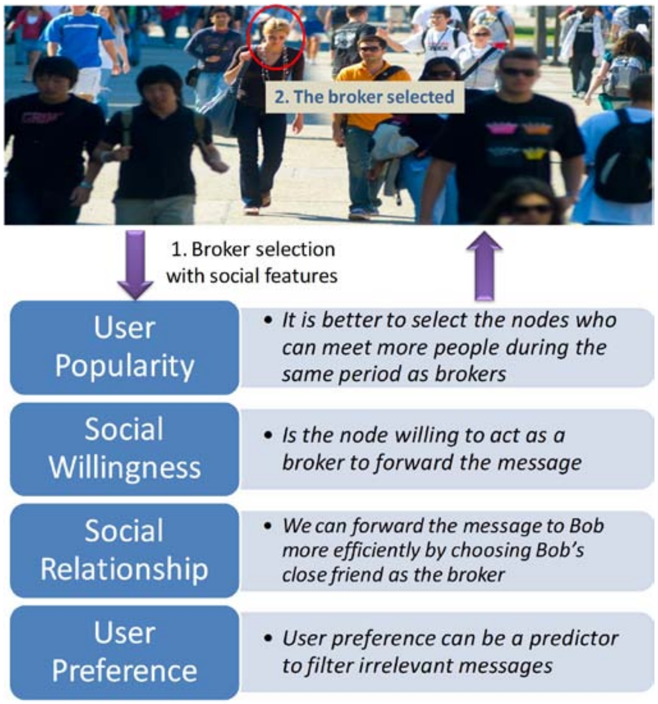

Figure 3. The Effect of Human Behaviors to Opportunistic IoT

III. APPLICATION AREAS

In addition to traditional IoT application areas, such as transportation and logistics, healthcare, and smart environments, among others, the human-centric nature of opportunistic IoT brings new potentials in many application areas. We present some of them in this section.

A. Opportunistic Social Networking

Forging social connections with others is the core of what makes us human. Opportunistic social networking (OSN) aims to improve social connectivity in physical communities by leveraging the information detected by mobile devices that contact. Social Serendipity is one of the earliest OSN studies, in which matching interests among nearby people who do not know one another are indicated as a cue for informal, face-to-face interactions [5]. In WhozThat [6], users within a public place (e.g., in a bar), who want to find someone interesting, can exchange their social network IDs through their mobile phone and check each other's profile data on the back-end profile server. ADESSO [7] builds an ad hoc community to facilitate the communication and service provision (e.g., community building, dating services) for users of physical proximity. From these examples, we can find that OSN will greatly bridge the gap between physical communities and online communities, and merge their merits to enhance human interaction.

B. Group Behavior Analysis

Deploying and using smart objects in organizations/enterprises facilitate communication and collaboration among co-located users, which also provides a way to record and understand organizational and societal behaviors. For example, the SixthSense project of Microsoft [8] uses RFID-tagged objects/devices to infer a range of enterprise intelligence, such as the interaction and association between people and workplaces. The collected data are then used for enterprise services, such as automatic bookings of conference rooms. Ara et al. [9] used specially designed work badges to study the relationship between productivity and interpersonal interactions in a workplace.

C. Opportunistic Advertising

When people connect, they influence and persuade. In opportunistic IoT, peer influence becomes more important than ever, which offers a wealth of new business opportunities. For example, several opportunistic advertising services that exploit human contacting in ad hoc networks have been developed recently. Bottazzi *et al.* [10] have proposed a place-dependent viral marketing solution that supports product advertisement distribution (e.g., forwarding promotional messages like coupons) among customers and their encounters in shopping malls, following the word-of-mouth model. The FleaNet [11] presents a virtual flea market service that works in urban vehicular networks to facilitate communications between co-located buyers and sellers of goods and to efficiently find matches of interest, using short-range radio techniques (the radio range is 250m).

IV. KEY CHALLENGES AND CONCERNS

Developing the potential benefits offered by opportunistic IoT poses a number of challenges and concerns. In facilitating the development of opportunistic IoT systems, a fundamental issue is the design of data dissemination protocols. Other important issues include heterogeneous social networking, privacy and security concerns, trust maintenance, and effective economic models.

A. Data Dissemination Protocols

Data dissemination in opportunistic IoT is a difficult problem. The heuristic behind the dissemination policy is that, since content providers and content consumers might be completely unaware of each other in a dynamic network, and never be connected at the same time to the same part of the network. Therefore, data objects should be moved and replicated in the network in order to carry them to interested users despite disconnections and partitions.

As presented in Section 2.2, to facilitate data dissemination and decrease its cost, the broker-based solution is often used. To this end, researchers start to explore *mobility patterns* and *co-location patterns* [10, 11] as key pieces of context information to predict nodes' activeness and estimate their "social popularity" to serve as brokers in the near future. Two basic assumptions are leveraged here: (1) The higher a node's popularity, the higher the chances of it meet more devices; and (2) all users are willing to act as brokers (the so-called "selflessness brokers"). However, the latter assumption does not always hold, since the brokers have to contribute computational resources during the data carrying and forwarding process. According to the social theories, socially selfish is a basic attribute of human beings [12, 13], which will affect human behaviors. Besides, preferences will also affect the behaviors of a broker. Therefore, we should measure the affects of various social features and taking consideration of them when designing data dissemination protocols for opportunistic IoT systems.

B. *Heterogeneous Social Networking*

With the development and prevalence of opportunistic social networking, people will live in heterogeneous social communities within cyber-physical spaces - both online communities and social networks where digital content is exchanged, and in the physical world, which exploits opportunistic contacting (i.e., face-to-face) between pairs of networked devices (e.g., smart phones) to exchange each other's content.

Different social networks have distinct technical features in terms of geographic coverage, infrastructure support, function time, and so on. This also leads to distinct human interaction patterns (e.g., comment/like in online communities, co-location in ad hoc communities) and implicit social knowledge (e.g., friendship/trustworthy/ influence in online communities, social popularity/movement patterns in ad hoc communities) that can be extracted from them. Study of the interaction between opportunistic and online social networks (e.g., how does online social network data mirror physical events), as well as merging their complementary features and fully combining their merits, however, become an important yet challenge research area.

Initial studies in this area are being conducted. For example, Lee *et al.* proposed a geo-social event detection method by mining unusually crowed places (e.g., reporting social events such as festivals or protests) from geo-tagged Twitter posts [14]. Our work, Social Contact Manager (SCM), has demonstrated how to merge the complementary features of online and opportunistic social networks, to automatically collect rich information (e.g., profile, face-to-face meeting contexts) about their contacts. The collected information can be leveraged to manage their contacts better, especially for efficient contact retrieval in name-slipping situations [15].

C. *Security, Privacy, and Trust*

The sharing of data in opportunistic IoT applications can raise significant privacy concerns, with information being sensitive and vulnerable to privacy attacks. For example, in opportunistic advertising services, sensitive personal information such as user location, mobility patterns, preferences may be used by data dissemination protocols. The new security challenge introduced here is the *protection of the privacy of participants while allowing their devices to reliably share/forward data in opportunistic IoTs*. Data anonymization techniques [16], which conceal the identity of users when they contribute/forward data, can be one way to deal with this problem, but there are still many issues to be addressed in the future.

In opportunistic IoT, anonymous contributors are often used as brokers to carry and forward data. If there lacks the control over ensuring source validity and information accuracy, data credibility issues may arise. For example, the source node may send incorrect data; brokers may modify the data it received and forward it to other nodes. Therefore, trust maintenance and abnormal detection methods should be built into opportunistic IoT systems to determine the trustworthiness and quality of the data being transmitted. However, traditional strategies often rely on online authentication from centric servers, which cannot meet the opportunistic connection and decentralized nature of opportunistic IoT systems. Taking consideration of the close tie between opportunistic networks and human social networks, it is promising to investigate the usage of social network structures and features in the design of trust models for opportunistic IoT.

D. *Incentive Mechanisms*

Opportunistic IoT offers immense potential to consumers and service providers. However, for these innovations to evolve from ideas to tangible products for the mass market, many commercial issues require resolution. For example, in broker-based data dissemination protocols, brokers need to contribute their computational resources to other nodes. However, the fact is that most opportunistic IoT devices (e.g., mobile phones, wearable sensors) have limited resources, such as energy and storage capacity. Therefore, the development of a solid economic model is highly important, and additional strategies for incentives and reputation for data contributors are needed (references are those explored in peer-to-peer systems [17] and ad-hoc networks [12]).

E. *Generic Infrastructure*

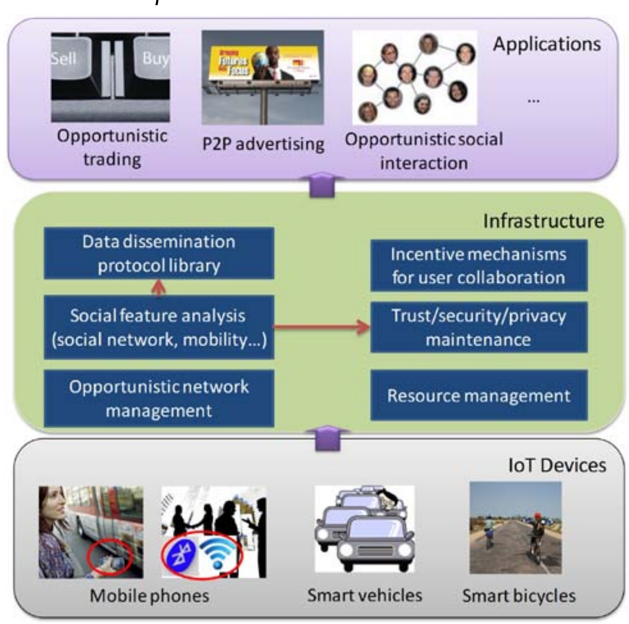

Figure 4. A reference architecture for opportunistic IoT.

To facilitate the development of opportunistic IoT, a generic infrastructure is essential. The infrastructure should provide a set of mechanisms for dynamic network management and information sharing among mobile nodes. It should address most of the issues mentioned in the previous subsections and provide a unique interface for information distribution/access by various applications. The basic components may include: opportunistic network management (dynamic, intermittent connectivity), trust/security/privacy maintenance (e.g., data anonymization, malicious node detection, data access control, data quality enhancement), resource management (e.g., bandwidth, storage, computing, energy), social feature extraction (e.g., social network analysis, user preference learning, mobility pattern mining), incentive mechanisms for user collaboration, and the library of various data dissemination protocols (flooding, popularity-based broker selection, and so on). Based on the concerns discussed above, we have proposed a reference architecture for opportunistic IoT systems, as shown in Fig. 4. It can be a starting point to build infrastructure-supported opportunistic IoT applications.

V. Conclusion and Future Vision

The IoT will harmoniously connect human, societies, and smart things in the future. The opportunistic IoT introduced in this paper is expected to explore the "harmonious" interaction between human and IoT, and discuss the social side of IoT. This theme is elaborated by describing the bi-directional effects between human and IoT, and potential application areas of opportunistic IoT. For the opportunistic IoT to be fully employed, numerous challenges remain to be addressed. All these challenges present substantial research opportunities for academic researchers, industrial technologists, and business strategists. We (Northwestern Polytechnical Univ. in China and Institut TELECOM in France) focus on the cross-field of pervasive computing and social science in the recent years. We have proposed the Social and Community Intelligence (SCI-11) vision in the Computer magazine [18], and organized the ACM First International Symposium on Social and Community Intelligence (SCI'11, in conjunction with UbiComp'11) [19]. We believe that the convergence of pervasive sensing technique, anthropology, and social science will greatly propel the development of IoT to its new stage, i.e., stepping into the era of the Social IoT.

Acknowledgements

This work was partially supported by the National Basic Research Program of China 973 (No. 2012CB316402), the National Natural Science Foundation of China (No. 61103063, 60903125), the Basic Research Foundation of Northwestern Polytechnial University (No. JC20110267).

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