An Overview of Opportunistic Ad Hoc Communication in Urban Scenarios

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Abstract—**In the era of the Internet of Everything, users with handheld or wearable devices equipped with sensing capability have become producers as well as consumers of information and services. The more powerful these devices get, the more likely it is that they will generate and share content locally, through ad hoc opportunistic connectivity, leading to the presence of distributed information sources and forwarders and the diminishing role of centralized, infrastructure-based servers. Despite this interesting portrait, the mobile and volatile nature of this network presents severe challenges demanding new networking techniques able to cope with the unpredictable and resource-constrained nature of mobile entities comprising it. In this context, we discuss novel data gathering and dissemination strategies in urban scenarios which do not rely on strict infrastructure mediation. While preserving the general aspects of our study and without loss of generality, we focus our attention toward practical applicative case studies which help us capture the characteristics of ad hoc opportunistic communication networks, and devise efficient solutions for use in real applicative contexts.**

Keywords—Ad Hoc Network, Internet of Everything, Opportunistic Communication, Urban Scenario

I. INTRODUCTION

Digital information has traveled for decades through wired-only links. Then, we had the advent of the wireless technology and shortly thereafter researchers proposed the Internet of Things, which envisioned connectivity among computers and different objects (e.g., home appliances). We can now go beyond and create technology that will enable the Internet of Everything (IoE), which will allow sharing any context-related digital resources and information, including data from RFID tag readers, IP cameras, user profiles, online reviews, augmented reality systems [1]. With interconnected devices that have recently surpassed in number people on Earth, our lives are immersed in a digital fountain with information produced everywhere around us. A user with a handheld or wearable device (e.g., smartphone or even Google Glass) equipped with sensing and communication capabilities can now be both producer and consumer of information and services.

One major advantage of infrastructure-based communication stands at enabling people to access their services regardless of their location. However, this is only partly true as the digital divide among people in different parts of the world, as well as among different groups within the same community, still exists [1].

In addition, this mobile revolution has brought an exponential growth of data traffic which is posing major stress on current infrastructure [2]. There is a need, now more than ever, for mesh and ad hoc networking techniques able to provide and extend connectivity where not present, or to alleviate the network stress by offloading data from infrastructure, or simply because more natural for location and proximity based applications [3], [4].

In this context, we aim to provide a general overview of novel data gathering and dissemination strategies in urban environments which rely on ad hoc opportunistic connectivity [5], [6]. To this aim, and without loss of generality, we focus on three practical case studies that allow us to practically understand challenges and possible solutions.

The rest of this paper is organized as follows. In Section II, we depict the considered general scenario. The three practical case studies we intend to address are presented in Section III, whereas solutions we propose for them are described in Section IV. Finally, Section V concludes this paper.

II. GENERAL SCENARIO

The urban environment represents a dense populated area, comprised by a multitude of actors, being them either human or non human, where the majority is equipped with a wireless interface. Every day encounters occur with us not knowing about it: moving in restricted physical spaces like university campuses, coffee shops, urban transportation means or everyday walking activities etc., give rise to a huge number of contact opportunities. The all-pervasive and ubiquitous nature of mobile devices equipped with a wireless interface and the everyday growing capabilities of the latter constitute an enormous unexploited resource, which we recently have began to recognize as such.

Answers to a query about a nearby object, an information source, a multimedia content, a process, a person, an experience, an ability, etc. could be answered locally. A locally published content might be consumed (consulted) just by being in proximity with it. The data, once checked, might be further disseminated in this local network of information exploiting the

mobility of the involved autonomous actors. This urban-wide data network grows and shrinks meeting the people's demand and vanishes whenever it is not required anymore (e.g., not alimented by the people). As opposed to multicasting techniques on infrastructure networks (e.g., Internet), here, the set of recipients is unknown, its cardinality is unpredictable and changes dynamically over time as a result of mobility and temporary disconnections. The data hence floats back and forth, from user to user, until it is not required anymore.

As of current practice we rely on infrastructure to provide the answer to a query. However, data in these settings are inherently local and have temporal validity. This is in contrast with the current infrastructure data model where data (almost) never expire, remaining globally available. In addition, accessing data that matters locally alleviates privacy concerns as users do not have to declare themselves on the communication platform and their identity can thus remain private. The data is created and consumed locally, alimented by the users and not owned by a third party.

III. CASE STUDIES

In the depicted general scenario discussed in Section II, we have identified key ingredients which could be employed in synergy with one another to deliver an urban-wide opportunistic communication platform, enabling message exchange amongst mobile users without strict infrastructure reliance. Below we enumerate and briefly discuss three practical case studies that are crucial to understand and enable the potential of the considered scenario.

Case Study 1 - Mobile-to-mobile Content Sharing. Content is increasingly being generated in a participatory fashion by the users themselves. There are scenarios where the content often has local significance and could be consumed locally without relying on infrastructure communication platforms. We could hence envision an ad hoc, opportunistic communication solution enabling content exchange when users are within close proximity of each other [7], [8]. To this end, we consider a content sharing solution enabling search and retrieval among mobile disconnected devices without infrastructure reliance. Nodes could exploit other nodes not only to share data, but also to delegate queries so as to explore the environment in a multihop delay tolerant fashion [9], [10].

Case Study 2 - Urban-wide Service Delivery. This case study encompasses autonomous actors present in urban areas that could be exploited to scale and boost opportunistic communications in a fully fledged urban environment. To this end, we consider an architecture employing the public transportation system (PTS) entities as a routing backbone, supporting elastic, non-real time service delivery [11]. The data delivery process could exploit the predictability of routes in the PTS and employ different routing algorithms and distribution policies also depending on the factual topology of the town. Both single- and multi-copy forwarding strategies could be devised to improve the forwarding process.

Case Study 3 - Floating Data. This case study introduces the concept of floating data. The rationale is that often the data has local and temporal validity, bound to a geographical area or explicitly imposed by a time attribute expressed by the metadata. The data once produced could be consumed (consulted) when in proximity, alleviating the need for publishing and making them available through infrastructure supported platforms. We hence consider the possibility for data to be maintained in an area for a certain amount of time thanks to replicas of these data stored on nodes passing by the area [12].

IV. PROPOSED SOLUTIONS

A. Case Study 1 - Mobile-to-mobile Content Sharing

Our aim is to devise a self-sustained content sharing solution through which mobile nodes could share and distribute content without relying on infrastructure. This mobile opportunistic network is comprised of human-operated mobile devices moving in restricted physical spaces, such as conferences, university campuses, refectories, clubs and in many other social settings. For instance, they could include networks of commuters sharing every morning and evening the same train/bus. In essence they are characterized by nodes with heterogeneous contact rates, unpredictable mobility and limited information.

In a content sharing context, low node density relates to a low data population, which if not addressed properly could undermine the system utility. To this end, M2MShare is a mobile-to-mobile content sharing solution tailored to the characteristics of the mobile disconnected networks [10], [13]. M2MShare introduces a novel technique aimed at addressing communication in sparse networks. It does so by providing the means for asynchronous data exchange similar to that pioneered by outer space DTNs [14]. In particular, content retrieval is performed by both disseminating a request packet in connected portions of the network but also by delegating the request, representing an unsatisfied, unaccomplished content retrieval task to encountered nodes.

Indeed, due to the distributed and dynamic nature of this environment, content producers and consumers might never be connected at the same time in the same network. Hence, a synchronous communication model does not always suffice. The delegation forwarding scheme addresses this issue by extending nodes' reach area to other connected local networks. When a node eligible for delegation, called servant node, is encountered, a request is issued and assigned. It is up to the servant to retrieve it and forward back the content once it encounters again the consumer. In synthesis, servant mobility is exploited to reach data content available in other standalone connected networks. A servant has the burden to perform the task and later on, when the consumer node is met, return its outcome (output).

In Fig. 1 we describe this scheme. A node at time T_i searches for specific data content in the local connected network it is immersed. As the content is not found, it is subject to the delegation process, triggered when certain criteria are met. At time T_{i+1} the servant node issues a query into a local connected network he is immersed (e.g., while commuting on a bus), resulting in the data content being found and retrieved. At time T_{i+2} the cycle closes with the servant forwarding the requested content to the consumer.
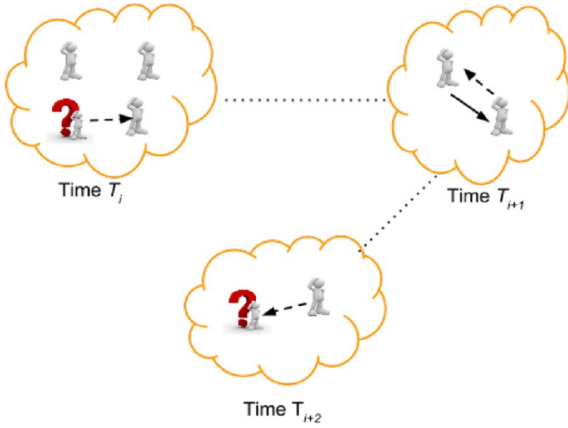
Fig. 1. Delegation forwarding exemplified.

To avoid excessive transmission overhead, requests are assigned only to frequently encountered nodes. Since no information about the producers is available the responsibility of finding that particular content is delegated to nodes that might be encountered again in the future. A critical aspect is the exploration of new mechanisms allowing nodes to expand their reach area to other connected portions of the network. This can be achieved by leveraging on node mobility and periodic encounters among users even if they are not aware of this social proximity (e.g., commuters utilizing the same train or bus every morning).

B. Case Study 2 - Urban-wide Service Delivery

A carrier-based approach may be more reliable than its human counterpart, mainly due to the quasi-deterministic node mobility: buses move along pre-determined paths and follow an *a priori* known schedule. Therefore, routing algorithms can be devised on reasonable assumptions and probabilistic predictions of encounters [15]-[17]. Despite its practical usage, even this scenario has a crucial and unsolved technical challenge: the scalability of the network when applied to larger areas, with growing number of lines, and a potentially huge offered load. Since size and shape of bus lines are limited by human and organizational factors, network delivery delay may ramp up with the covered area due to the increasing number of hops each packet must traverse.

In this context, Mobile Delay/Disruption Tolerant Network (MDTN) is a delay tolerant application platform built on top of a PTS and is able to provide opportunistic service connectivity for elastic applications [18].
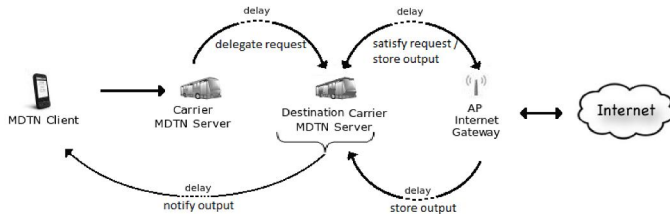

Fig. 2. MDTN system orchestration.

In Fig. 2, the three main entities involved in the architecture are depicted: (i) the MDTN client or a mobile user operating a wireless-equipped handheld device, (ii) the MDTN server or the wireless data carrier which locally stores users' requests and tries to fulfill them when Internet connectivity is available, and (iii) the Internet Gateway (IG), which is an Internet-enabled wireless access point deployed at bus terminals. We have considered positioning IGs at bus terminals since these are joint points between different bus lines and because the bus company may already have an infrastructure-based end point there (e.g., offices). However, we do not preclude the possibility of a different IG distribution scheme if deemed more practical or providing significant performance improvement.

The basic functionality of MDTN is as follows. Once the user gets on board of the carrier (e.g., the bus), she/he establishes a connection with the on-board hosted server (a base station hosting the MDTN server) and issues a request. The request consists of a content identifier (e.g., an URI) and a destination bus line where the user is going to pick up the response later on. The goal of MDTN is to provide the user with the desired content at the specified bus line. After the request has been issued, it is opportunistically forwarded by the carrier toward one of the IGs and, finally, the response reaches the bus line where the content is expected.

The process described above involves a multi-hop opportunistic routing of both requests and results from carriers toward one of the IGs and from the IG toward the destination bus line. The delivery process is independent from the underlying routing strategy and occurs as follows.

- If the carrier holding the request encounters during its trip a carrier belonging to a valid (based on the adopted routing strategy) next-hop line, the request is forwarded. It is now up to the new carrier to satisfy the request if it reaches its end of line;

- If the carrier holding the request reaches its terminal it is able to fulfill the request by itself; the response will be forwarded toward the destination line.

- If the response reaches a destination line carrier, dissemination of the response among carriers of the same line can take place. In this phase, forwarding occurs during opportunistic contacts between destination line carriers (if any).

The rationale behind the last step of the delivery process is that there might be several carriers travelling on a destination line and response dissemination among them can speed up the delivery process.

Once in proximity with the wireless carrier, the client establishes a connection with the MDTN server to receive the request outcome when/if the request has been accomplished. Obviously, the MDTN client can disconnect/connect from/to the MDTN server at any time and the outcome will be forwarded the next time they pair with each other. The delivery process is entirely transparent to the client. It is also important to note that the proposed system could provide the user with both pull/push style services.

C. Case Study 3 – Floating Data

Surprisingly, the more we expand our interconnecting possibilities, the more we are interested in local, context-related information. Think for instance of Facebook's success: even with the possibility to connect with anyone in the world, its main use is focused on our limited social context and people we already know. Another interesting example is represented by the revolutionary wave of demonstrations and protests that has recently flooded the Arab world, whose local coordination has massively relied on social networks such as Twitter.

In many urban scenarios data have temporal and geographical validity bounds depending on attributes or use. Once retrieved, data might be disseminated further and a mechanism might be required to guarantee data availability (survivability) in the Area of Interest (AoI). The diameter of this network of data grows and shrinks, and eventually vanishes depending on the users' demands. As an example, any instant advertising of goods, attractions, events and/or news could be consumed locally, disseminated and kept alive in a certain AoI, with data moving back and forth, from user to user: hence the name *floating data* [12].

This case study is comprised of mobile entities producing and consuming data. Nodes in an AoI, exchange information in opportunistic fashion if they are in transmission range of each other. When leaving the AoI, nodes can discard the acquired messages. Obviously, there is no guarantee of information availability due to the unpredictable nature of human mobility. We identify as the characteristics of data anchoring technique the survivability and accessibility of the data. Survivability means that the information is somewhere near the AoI, while accessibility refers to functionalities needed to access the information stored on nearby devices.

The concept of data anchoring can be applied to different kinds of scenario, ranging from urban tagging to emergency. An urban tagging application can be deployed dense urban areas with users providing data anchoring. Each user might exploit this service to disseminate information concerning warnings or even accessibility related information [19]. Information regarding path holes or the presence of thieves in her/his neighborhood could be made available. Such a solution could even be employed to coordinate people in government uprising scenarios. In these settings, data is alimented and controlled by users, in contraposition of data models where data is made available indefinitely through a remote server in the infrastructure (e.g., the Internet).

V. CONCLUSION

In this work, we aimed to go beyond infrastructure based communication platforms and discuss technology that will enable the Internet of Everything paradigm, allowing sharing and distribution of content among mobile disconnected devices without strict infrastructure reliance. A user with a handheld or wearable device, equipped with sensing and communication capabilities can be both producer and consumer of information and services. We pursued our investigation by means of three applicative case studies, with emphasis on the techniques aimed at supporting them. This overview allowed us to improve our comprehension of the technology that could be used in synergy to sustain an urban-wide opportunistic ad hoc communication.

REFERENCES

[1] S. Ferretti, M. Furini, C. E. Palazzi, M. Roccetti, P. Salomoni, "WWW Recycling for a Better World", Communications of the ACM, ACM, vol. 53, no. 4, Apr 2010, pp. 139-143.

[2] A. Bujari, "A Survey of Opportunistic Data Gathering and Dissemination Techniques", in Proc. of IEEE ICCCN, Munich, Germany, Jul 2012.

[3] L. De Giovanni, C. E. Palazzi, "Optimal Client-Server Configuration of Mobile Ad-Hoc Networks", Elsevier Electronic Notes in Discrete Mathematics, vol. 41, no. 5, Jun 2013, pp. 495-502.

[4] A. Hamidian, C. E. Palazzi, T. Y. Chong, J. M. Navarro, U. Körner, M. Gerla, "Deployment and Evaluation of a Wireless Mesh Network", in Proc. of the Second IARIA/IEEE International Conference on Advances in Mesh Networks (MESH 2009), Athens, Greece, Jun 2009.

[5] S. Biswas, R. Morris, "Opportunistic Routing in Multi-hop Wireless Networks", SIGCOMM Comput. Commun. Rev., vol. 34, no. 1, Jan 2004, pp. 69-74.

[6] C. Boldrini, M. Conti, A. Passarella, "Contentplace: Socialaware Data Dissemination in Opportunistic Networks", in Proc. of ACM MSWIM'08, Vancouver, BC, Canada, Oct 2008.

[7] C. E. Palazzi, A. Bujari, E. Cervi, "P2P File Sharing on Mobile Phones: Design and Implementation of a Prototype", in Proc. of IEEE International Conference on Computer Science and Information Technology, Beijing, China, Aug 2009.

[8] C. E. Palazzi, A. Bujari, "A Delay/Disruption Tolerant Solution for Mobile-to-Mobile File Sharing", in Proc. of IFIP/IEEE Wireless Days 2010, Venice, Italy, Oct 2010.

[9] A. Bujari, C. E. Palazzi, D. Bonaldo, "Performance Evaluation of a File Sharing DTN Protocol with Realistic Mobility", in Proc. of IFIP/IEEE Wireless Days, Niagara Falls, ON, Canada, Oct 2011.

[10] C. E. Palazzi, A. Bujari, "Social-Aware Delay Tolerant Networking for Mobile-to-Mobile File Sharing", Wiley International Journal of Communication Systems, vol. 25, no. 10, Oct 2012.

[11] C. E. Palazzi, A. Bujari, S. Bonetta, G. Marfia, M. Roccetti, A. Amoroso, "MDTN: Mobile Delay/Disruption Tolerant Network", in Proc. of IEEE ICCCN 2011, Maui, HI, USA, Aug 2011.

[12] A. Bujari, D. Maggiorini, C. E. Palazzi, L. Ripamonti, H. Sadushi, "Geo-Anchored Floating Data for Mobile Users", in Proc. of IEEE ICME/NIME 2013, San Jose, CA, USA, Jul 2013.

[13] A. Bujari, C. E. Palazzi, M. Roccetti, G. Marfia, "DTN Content Sharing among Commuters", International Journal of Satellite Communications Policy and Management, Inderscience Pub., vol. 1, no. 2/3, Oct 2012.

[14] S. Burleigh, A. Hooke, L. Torgerson, K. Fall, V.Cerf, B. Durst, K. Scott, H. Weiss, "Delay-Tolerant Networking: An Approach to Interplanetary Internet", IEEE Communications Magazine, vol. 41, no. 6, Jun 2003, pp. 128-136.

[15] C. Quadri, D. Maggiorini, S. Gaito, G. P. Rossi, "On the Scalability of Delay-Tolerant Routing Protocols in Urban Environment", in Proc. of IFIP/IEEE Wireless Days 2011, Niagara Falls, ON, Canada, Oct 2011.

[16] X. Zhang, J. Kurose, B. N. Levine, D. Towsley, H. Zhang, "Study of a Bus-Based Disruption-Tolerant Network: Mobility Modeling and Impact on Routing", in Proc. of ACM MobiCom'07, Montréal, QC, Canada, Sep 2007.

[17] S. Gaito, D. Maggiorini, G. P. Rossi, "Bus Switched Networks: An Ad Hoc Mobile Platform Enabling Urban-Wide Communications", Elsevier Ad Hoc Networks Journal, vol. 10, no. 6, Aug 2012, pp. 931-945.

[18] A. Bujari, C. E. Palazzi, D. Maggiorini, C. Quadri, G. P. Rossi, "A Solution for Mobile DTN in a Real Urban Scenario", in Proc. of IEEE WCNC/WVCN 2012, Paris, France, Apr 2012.

[19] C. E. Palazzi, L. Teodori, M. Roccetti, "PATH 2.0: A Participatory System for the Generation of Accessible Routes", in Proc. of the IEEE International Conference on Multimedia and Expo (ICME'10), IEEE, Singapore, Jul 2010.