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Editorial

Cyber-physical systems for Mobile Opportunistic Networking in Proximity (MNP)

The pervasive presence of mobile personal devices like smartphones, tablets, and similar smart devices, together with the massive use of online social networking services (e.g., Facebook, Twitter, Google Plus, LinkedIn, etc.) are increasingly creating a cyber-physical space where users can interact exploiting and generating information. Enriched with several sensing capabilities and networking interfaces, today's portable devices are enabling new ways of communication including Mobile Networking in Proximity (MNP) [1]. This network mode complements the classic scenario with Internet coverage by enlarging the range of functionalities of these devices through short-range communications (e.g., Bluetooth, Wi-Fi Direct, etc.). Even with the wide coverage of the Internet, there are still some situations where the traditional network is overloaded, unavailable, or too expensive. In such situations, when two devices are in proximity, they could still share information by just exploiting the meeting opportunities and activating an opportunistic hop-by-hop forwarding towards the destination.

Due to the dynamic and intermittent nature of encounters between mobile devices, MNP needs to operate under a specific network paradigm to manage the sparse topologies often created by these devices. Specifically, a *store-carry-forward* mechanism is used, which allows mobile nodes to store messages, carry them while moving, and forward those messages to other suitable nodes (next-hop or destination nodes) when encounter opportunities arise. Recent studies have shown that a social-based logic is the most promising choice for selecting the intermediate nodes to which forward a packet during an encounter [2]. The basic idea is that exploring human behavior, the meeting patterns between mobile nodes can be predicted with a certain accuracy thus maximizing the chances of delivering a message to its destination. In this view, social-inspired mobile networking research is increasingly underlining the benefits and the need of having knowledge of the social behavior of users for the MNP-based design. On one hand, the social behavior of mobile nodes can be extracted from the mobility of nodes. On the other hand, also online social network interactions may provide information about user's social behavior [3]. As such, the convergence between these two worlds, the physical offline one made by mobile devices and the cyber online one made by the online social networks is becoming increasingly important, opening a novel and interesting research field with many challenging issues.

The purpose of this special issue is to depict the current state-of-the-art of the research closely related to mobile and social networking, and in particular, to cyber-physical MNP, by reporting advances on approaches, methods, and applications addressing the new challenges in this field. In response to this highly specific call for papers, we received 20 manuscripts from all over the world. We were pleased to discover that 12 of these papers were very good candidates for this special issue. As such, after at least two review rounds, we selected and accepted them. Each of these papers was carefully reviewed by Guest Editors and at least two experts in various fields including opportunistic networks, DTNs, VANETs, IoT, mobile social networks, complex networks, mobile applications, crowd computing, and security in mobile environments. In the following, we will overview the 12 papers included in this special issue that reflect the recent advances in cyber-physical MNP. We organized them in four research areas: (a) message diffusion and routing, (b) middleware, (c) mobility modeling and management, and (d) trust management.

Message diffusion and routing

Due to the intrinsic social-based nature of human encounters, message dissemination in MNP is usually performed taking into account the social links between the mobile nodes. In this way, nodes are able to construct forwarding paths able to cope with intermittent connections, network partitions and long delays typical of such environments. Modeling the social behavior of a node, however, is extremely challenging due to the variability of a user's personal features. In *"Pervasive Forwarding Mechanism for Mobile Social Networks"*, Machado et al. propose a message dissemination scheme for MNP considering external factors such as temperature and seasonal calendar as environmental features capable of modeling users' social profiles in terms of preferences and future encounters. The results of a preliminary analysis on real data from weather and human mobility depict social interactions and spatial features that change as the thermal conditions vary. As such, the authors propose a cyber-physical socially-aware message forwarding scheme adaptable to the seasonality of personal preferences. The experiments evaluating this scheme indicate that temperature is an important feature able to improve the forwarding decision process.

The analysis of social data, even if on one hand is able to guide and improve message forwarding, on the other hand reveals personal data, thus potentially compromising the privacy of nodes. The paper *"4PR: Privacy Preserving Routing in Mobile Delay Tolerant Networks"* by Miao et al. proposes a Privacy Preserving Probabilistic Prediction-based Routing (4PR) protocol that forwards

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messages taking into account aggregated information about communities instead of individual nodes. Specifically, this scheme exploits the probability that at least one node in a community will encounter the destination node by hiding the individual mobility pattern of a node. The presented theoretical security analyses together with practical performance evaluations demonstrate that 4PR has routing performance comparable to existing prediction-based protocols. Additionally, the community information is computed efficiently and independently from the routing protocol.

In *"Characterization and Applications of Temporal Random Walks on Opportunistic Networks"*, Ramiro et al. study the use of Temporal Random Walks (TRWs) as a simple method to deliver messages while limiting the number of message replicas usually used to route messages in MNP environments. TRWs are capable of adapting themselves to the self-organizing evolution of MNP. Specifically, a TRW can be seen as the passing of a token among nodes on spatio-temporal paths. The authors propose to use contacts as a medium to pass a specific item (the token) gathering messages, rather than to route packets. First, studying the drop ratio for message forwarding considering finite buffers, the obtained upper-bound for the drop ratio results in being independent of the encounter rate. Then, by exploring token-sharing as the routing mechanism, results demonstrate that the use of TRWs are able to increase the delivery probability, keeping at most as many copies of a message as the number of tokens available. Finally, TRWs are used as a monitoring method for crowdsourcing scenarios, demonstrating that the characteristic of the intercontact times (ICT) between nodes can be approximated only by collecting a subset of global information.

For the effective design of novel services for MNP, a key challenging topic is the modeling of the performance of such networks in terms of contact-based messaging. The paper *"Analytical Evaluation of the Performance of Contact-Based Messaging Applications"* by Hernández-Orallo et al. analytically models the performance of mobile opportunistic networks by taking into account aspects such as the density of people, the dynamics of arrivals and departures to and from a given location, the message size, and the durations of contacts. Building the model on *Population Processes*, which are commonly used to describe the dynamics of biological populations, the evaluation performed on this model shows that it is able to reproduce the dynamics of message diffusion applications. Specifically, as the density of people increases, the effectiveness of the diffusion of messages is improved. Moreover, when this density is low, the influence of the arrivals and departures of nodes on diffusion is more relevant. Finally, large message sizes are shown to reduce the effectiveness of epidemic diffusion.

In *"Situation Awareness and Computational Intelligence in Opportunistic Networks to Support the Data Transmission of Urban Sensing Applications"* by Rolim et al., the problem of routing through a MNP approach is considered in an urban environment. Smart cities, in fact, can be seen as a large-scale cyber-physical system with sensors monitoring both cyber and physical indicators that will be able to dynamically change the urban environment in order satisfy the users' needs. To support the data transmission of urban sensed data, an engine that uses MNP is proposed. It applies situation awareness and computational intelligence to perform routing, adaptation, and decision-making procedures. In particular, the proposed engine is intended to be used within the communication component of a large-scale architecture called *UrboSenti*. Several simulations carried out within a simulated urban environment show that this engine has 12% less overhead than other benchmark routing approaches for MNP scenarios.

Another interesting aspect of message dissemination in MNP is the multicast approach for which a source node sends a message to multiple destinations. The multicast service often occurs in MNP. For example, in conference scenarios, presentations are delivered to the attending people for informing them of news. In disaster scenarios, just to provide another example, alerts on local conditions and hazard levels are usually disseminated to groups of rescue workers. In *"Efficient Multicast Algorithms in Opportunistic Mobile Social Networks using Community and Social Features"* by Chen et al., to improve multicast efficiency, a multicast algorithm using dynamic social features and community structure is proposed. Differently from most of the existing algorithms using static social features to capture nodes' contact behavior, two novel multicast algorithms considering dynamic social features and more relationships among nodes are proposed. The first algorithm, called Multi-CSDO, involves only destination nodes in community detection while the second one, called Multi-CSDR, involves both the destination nodes and the nodes suitable as relays in community detection. Simulation results using two real-world traces show that the two multicast algorithms are able to outperform the existing ones in terms of delivery rate, latency, and number of forwardings.

Middleware

Applications supporting social networking in proximity are increasingly becoming popular since they are able to create a cyber-physical environment augmenting both face-to-face and online interactions. Think, for example, of smartphone applications locating nearby Facebook friends and incentivizing encounters. Such applications, however, mainly use Internet connection even if most of the connections happen locally. In *"Padoc: Enabling Social Networking in Proximity"*, Holzer et al. present an iOS middleware for social networking in proximity that provides multihop MNP support when Internet connection is not available. The paper evaluates several MNP message diffusion strategies offered by Padoc and presents Heya, a novel colocated classroom interaction system built on top of Padoc. Heya allows creating chat rooms for writing posts and rating them. Tested on a mission with MSF (Médecins Sans Frontières), Heya shows itself to be a first concrete deployment example in the field of applications for social MNP.

In *"Cocoon: A Lightweight Opportunistic Networking Middleware for Community-oriented Smart Mobile Applications"* by Turkes et al., a lightweight middleware for any kind of mobile platform (e.g., Android, iOS, Windows Phones) is proposed. Designed above Wi-Fi and Bluetooth standards, Cocoon does not require any modifications or configurations of the affiliated wireless interfaces, facilitating fast and reliable information sharing between any kind of MNP nodes (e.g. smartphones, smart watches, tablets, etc.). This community-oriented context-aware middleware supports two specialized networking models, a connection-free model for highly mobile but low-throughput scenarios, and a connection-based model for group communications under high network stability. Both models exploit opportunistic beacons (i.e. information-encoded wireless network identifiers) for switching data between devices. Studied over a set of real-world experimental network setups, Cocoon shows itself to be a promising MNP service to be used for general purpose applications.

Mobility modeling and management

Node mobility is fundamental for MNP: the more people move, the more the messages spread through the networks. As such, mobility modeling and management are the basis of dissemination choices. Mobility modeling in particular, requires accurate knowledge of human behavior. Recent models [4] consider, for example, both (online and offline) social and spatial factors. However, the techniques used to capture such factors, are usually able to capture either positions, or contacts, with a limited accuracy. In *"SOUK: Spatial Observation of hUman Kinetics"*, Killijian et al. propose a method to gather positions and orientation of mobile nodes even in a crowd, with great accuracy. The developed open-source software pipeline is able to extract several metrics on movement like position and orientation, and social contacts allowing the analysis of their relationships and with the long-term goal of refining mobility models or deriving new ones. For demonstrating the accuracy and the validity of such an approach, the motion of 50 individuals was traced through the SOUK platform and compared against random way-point models having the same global characteristics. Results demonstrate that group- and interaction-based models are required to fully exploit the benefits of MNP since human kinetics cannot be accurately predicted by a random way point model.

As far as mobility management is concerned, in *"Multi-criteria Optimization of Wireless Connectivity over Sparse Networks"*, Ojog et al. propose a machine learning algorithm to improve node connectivity through a smarter Wi-Fi access point choosing heuristic. Specifically, the algorithm balances signal strength, latency, bandwidth, and, most importantly, the number of friends predicted to connect to the respective access point. The results of the simulations on real-world datasets show that the proposed algorithm increases the likelihood of contacts, also distributing social subgraphs of users over wireless networks while improving the overall hit rate. Furthermore, the proposed solution is feasible even on large sets of nodes and for long time periods.

Trust management

In MNP, mobile nodes should operate in a cooperative way for forwarding their messages. However, in the real world, some nodes may avoid forwarding messages belonging to other nodes in order to save their own resources. A trust mechanism is thus needed in a MNP to deal with node selfishness and more generally, to avoid malicious behavior. To this end, the paper *"SNVC: Social Networks for Vehicular Certification"* by Oliveira et al. focuses on trust aspects in vehicular MNP where humans as well as vehicles contribute information about the traffic and road conditions. This paper proposes social networks as a form of certification mechanism between vehicles allowing the system to exchange messages asserting the trust and reputation of information sources. Through contacts, nodes can establish trust sharing keys to warrant their identity and signing certificates. A certificate signed by a friend on the social network can be validated if the public key of this friend is available. Moreover, a reputation system is proposed to ensure reliable information. Evaluating SNVC on real-world traces of vehicular mobility, the results show that trusting friends is able to improve message exchange and the proposed reputation mechanism well promote reliable nodes.

Another trust-based scheme is proposed in the paper *"Trust-based and Social-aware Coalition Formation Game for Multihop Data Uploading in 5G Systems"* by Militano et al. Within this work, a trust-based coalition formation game to model cooperative content uploading in 5G cellular Device-to-Device (D2D) communications is proposed. For establishing the trustworthiness of nodes and defining node reputations, social-based indicators are used. A constrained coalition formation game where nodes are assumed to be rational self-interested players aiming at maximizing their uploading time gain is studied. This coalition formation game considers both coverage constraints and trust constraints. Exploiting this study, the authors propose a cooperative and opportunistic hop-by-hop forwarding scheme saving energy and filtering out malicious nodes. Simulations show that the social-based trusted solution guarantees higher gains in content uploading time and increases the number of successful cooperative interactions.

List of reviewers

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A. Socievole*
DIMES, Ponte P. Bucci, University of Calabria, 87036, Arcavacata di Rende (CS), Italy

A. Ziviani
National Laboratory for Scientific Computing (LNCC), Av. Getúlio Vargas, 333 - Quitandinha 25651-075, Petrópolis, RJ, Brazil

F. De Rango
DIMES, Ponte P. Bucci, University of Calabria, 87036, Arcavacata di Rende (CS), Italy

A.V. Vasilakos
Lulea University of Technology, Department of Computer Science, Electrical and Space Engineering, Skellefteå, Sweden

E. Yoneki
University of Cambridge Computer Laboratory, JJ Thomson Avenue Cambridge, CB3 0FD, United Kingdom

*Corresponding author. Present address: DIMES Cubo 41 C, Ponte P. Bucci, University of Calabria, 87036 Arcavacata di Rende (CS), Italy.

E-mail addresses: socievolea@dimes.unical.it (A. Socievole), ziviani@lncc.br (A. Ziviani), derango@dimes.unical.it (F. De Rango), athanasios.vasilakos@ltu.se (A.V. Vasilakos), eiko.yoneki@cl.cam.ac.uk (E. Yoneki)

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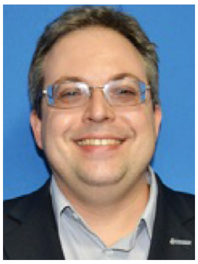
Annalisa Socievole (http://culture.deis.unical.it/telelab/homepage_AS) is a Research Fellow in the Department of Informatics, Modeling, Electronics and Systems Engineering (DIMES) at University of Calabria (Italy). She received a Ph.D. in Systems and Computer Science Engineering in February 2013 and a master's degree in Telecommunications Engineering in July 2009, both from the University of Calabria. From October 2011 to April 2012, she has been a visiting Ph.D. student in the Systems Research Group of Cambridge Computer Laboratory (UK) under the supervision of Prof. Jon Crowcroft and Dr. Eiko Yoneki. From October 2013 to June 2014, she has been Post-Doc Researcher at TU Delft within the Network Architecture and Services Group chaired by Prof. Piet Van Mieghem. Her research interests include Opportunistic Networks, DTNs and social networks.



Artur Ziviani (http://www.lncc.br/~ziviani) is a Senior Researcher at the National Laboratory for Scientific Computing (LNCC), a research unit of the Brazilian Ministry of Science, Technology, Innovations, and Communications (MCTIC) located in Petrópolis, Brazil. In 2003, he received a Ph.D. in Computer Science at the LIP6 laboratory of the Université Pierre et Marie Curie (Paris 6) – Sorbonne Universités, Paris, France, where he has also been a lecturer during the 2003–2004 academic year. He received a B.Sc. degree in Electronics Engineering in 1998 and a M.Sc. degree in Electrical Engineering (emphasis in Computer Networking) in 1999, both from the Federal University of Rio de Janeiro (UFRJ), Brazil. From September 2008 to January 2009, he was a visiting researcher at INRIA in France. His current research interests include network characterization, modeling, and analysis, network science, and interdisciplinary research with a networking approach. He is a Member of SBC (the Brazilian Computer Society), an Affiliated Member of the Brazilian Academy of Sciences, and a Senior Member of both IEEE and ACM.

Floriano De Rango (http://culture.deis.unical.it/derango) is Assistant Professor in the Culture Group within the DIMES Department at University of Calabria. He received a master degree (cum laude) in Computer Science Engineering in October 2000, and a Ph.D. in Electronics and Communications Engineering in January 2005, both at University of Calabria. He has been TPC member of many international conferences such as IEEE VTC, ICC, WCNC, Globecom, Med Hoc Net, SPECTS, WirelessCOM, and WinSys, and reviewer in many journals such as IEEE Communication Letters, JSAC, IEEE Transactions on Vehicular Technology, Computer Communication, Eurasip JWCN and WINET. He is involved also in the standardization activities of the 6tisch IETF group concerning the design of protocols for sensors in industrial sectors. His research interests include Satellite Networks, IP QoS architectures, Adaptive Wireless Networks, Ad hoc Networks, Pervasive Computing and Ultra Wideband Technology.

Athanasios V. Vasilakos (http://www.athanasiosvasilakos.gr/) is Professor with the University of Western Macedonia, Kozani, Greece. He has authored or coauthored over 200 technical papers in major international journals and conferences. He has authored or coauthored five books and 20 book chapters in the areas of communications. He has served as the General Chair, the Technical Program Committee (TPC) Chair, and a TPC Member (i.e., INFOCOM, SECON, and MOBIHOC) for many international conferences. He served as an Editor or a Guest Editor for many technical journals, such as the IEEE Transactions on Network and Service Management, the IEEE Transactions on Information Forensics and Security, the IEEE Transactions on Systems, Man, and Cybernetics, Part B, the IEEE Transactions on Information Technology in Biomedicine, the IEEE Transactions on Computers, the ACM Transactions on Autonomous and Adaptive Systems, the IEEE Journal on Selected Areas in Communications, the IEEE Communications Magazine, the ACM Wireless Networks (Springer), and the ACM Mobile Networks and Applications (Springer). He is a Founding Editor-in-Chief of the International Journal of Autonomous and Adaptive Communication Systems and the International Journal of Arts and Technology. He is also the General Chair of the Council of Computing of the European Alliances for Innovation.

Eiko Yoneki (http://www.cl.cam.ac.uk/~ey204/) is an EPSRC Research Fellow at the University of Cambridge Computer Laboratory. She has received a Ph.D. in Computer Science from the University of Cambridge on 'Data Centric Asynchronous Communication'. Her research spans distributed systems, networking, and databases. Her recent work focuses on designing algorithms and modeling dynamic networks inspired by social science and complex networks. She leads the EPSRC Data-Driven Epidemiology project, the Data-Driven Declarative Networking with Microsoft Research, and the EU FP7 eCOUSIN, Enhanced Content Distribution with Social Information. She has also participated in the Haggle, Socialnets, and Recognition projects.