Internet of People (IoP)

An inter-disciplinary approach to Networking in a human-centric NGI

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***Abstract*— The vision of NGI as a human-centric complex socio-technical system is supported by several trends, spanning the technological, social and behavioral domains. In this position paper, we argue that, from this trend, it naturally follows that well-establish quantitative models of the human individual and social behavior need to be embedded into the design and operation of NGI *networking* protocols. Therefore, NGI becomes an *Internet of People*, because NGI devices become proxies in the Internet of their human users, and thus can use, when appropriate, the same behavioral functions that their human users would use when interacting with each other. In the paper, we present the details and the key paradigms of the IoP approach, describe successful prior experiences in adopting it, and identify key research challenges in the framework of NGI.**

I. INTRODUCTION

Many trends strongly indicate that human-centric networking will have a relevant role in NGI. On the one hand, Cyber-Physical Convergence is making the Internet and the physical worlds more and more intertwined and interdependent [10]. The terrific diffusion of mobile personal devices, which are both data consumers and producers, is extending the Internet well beyond its core. Network functions are more and more pushed towards the edges of the Internet [8][17], making – in perspective - users' personal devices "first-class citizens" in the provisioning and operation directly at the edge of Internet functions. In the NGI perspective, these trends are likely to make humans not merely the *final users* of services and applications provided from a core Internet (or from the cloud) operated by third parties, but – through their personal devices – they will be *active elements* of applications, services, and also *network functions* provisioning. In many cases, network services will be device-centric, in the sense that users' devices will "take the initiative" and determine how the network needs to be configured and operated to satisfy their requirements. They will dynamically configure the network to access devices nearby as well as remote devices, thus having an active role in deciding how local networking resources as well as resources accessible through the core infrastructure will be used. Users' devices and core infrastructures will thus collaborate (often under devices' initiative) to provide network functions.

In this view, users' personal devices become proxies of their human users in the Internet, and therefore their users' behavior (both individual and social) becomes an important design element not only for high-level services and applications, but also for the design of networking protocols. Accordingly, the NGI evolves towards an *Internet of People (IoP)*: all networking functions take into consideration that Internet devices can be users' personal devices, and therefore exploit models of the human behavior to determine the way these devices should operate in the network. Stretching this further, the IoP concept embraces even a tighter integration between NGI devices and humans, allowing humans themselves to contribute resources to NGI functions, evolving current rudimentary examples such as crowdsourcing and crowdsensing.

A few key elements are at the basis of our view of IoP.

- *IoP is inter-disciplinary*. Because facets of the human behavior need to be "coded" into networking protocols, we need well-established models that describe relevant aspects of the human individual and social behavior, derived in "non-ICT" disciplines. These models will have to be embedded into networking protocols and devices logic, to influence the operations of the networking functions.
- *IoP is quantitative (not qualitative)*. Although inter-disciplinary and involving human sciences, the goal of the IoP approach is to design networked systems for NGI. Therefore, human behavioral models need to be quantitative, expressed, e.g., in forms of mathematical or algorithmic models and validated by the relevant research communities that study the modeled facets of the human behavior. Qualitative models that are "interpreted" by Internet researchers generating "human-inspired" networking protocols have shown to be not particularly successful in the past, and IoP must depart from this approach.
- *IoP has a technological focus*. Although NGI needs to take into consideration many aspects of the interactions between humans and Internet technologies, such as adoption, policy, governance and legislative aspects, IoP is a strictly technology-based approach to design NGI protocols and systems.
- *IoP is networking*. While sometimes IoP has been conceived as an application or service-oriented approach, we firmly believe that IoP has a huge potential to guide the design of the NGI networking solutions, thus permeating all functional layers (represented currently in

the TCP/IP stack). Prior experiences (described in the paper) show that IoP approaches to design networking solutions are successful.

- *IoP embraces data-oriented Internet functions.* Due to the increasing importance of data in the Internet ecosystem, we believe that NGI will be (also) a data-centric network, i.e., data-centric services will be part of the NGI core functions. The IoP concepts can be used not only to re-design "conventional" networking functions, but also to design data-centric network functions as a core part of NGI, as already demonstrated in some initial cases described in the paper.

In the following of the paper we describe in more in detail the IoP concept in the framework of NGI (section II), discussing its motivation, concepts, key paradigms and prior experiences. Then, Section III describes some of the key research challenges we envision for IoP.

II. IoP in the Context of NGI

A. IoP as the way to build a human-centric NGI

The diffusion of personal (mobile) devices and pervasive networking and computing technologies is expected to exponentially increase in the next few years (for example, CISCO foresees a eightfold increase of mobile data traffic between 2015 and 2020, with a compound annual growth rate (CAGR) of 53% [8]). This is increasingly pushing the vision of Cyber-Physical Convergence, discussed for instance in [10]. According to this vision, the physical world of the users and the cyber world of Internet applications and services are more and more integrated and converging. Data generated in the physical world (e.g., by sensors embedded in personal users' devices and physical infrastructures) flows to the cyber world, where it is elaborated and exchanged. On the other hand, interactions in the cyber world result in actions in the physical world, e.g., because users modify their behaviour based on information received through Internet applications, or because physical infrastructures are configured through actuators.

In addition to Cyber-Physical Convergence, a second key trend that will impact NGI is the progressive shift of networking functions from the core to the edge of the network [13] [17]. The conventional Internet was designed (and is still designed) under the assumption that all networking functions are provided by core network devices, which are responsible to "build" the required network abstractions. More recently, to cope with the increased complexity and performance requirements of Internet applications, middleboxes and overlay network infrastructures (e.g., CDNs) became commonplace, to the point that we can consider them as an additional set of standard Internet functions. But, still, basically no such system incorporates edge devices as key elements in the provision of Internet functions. However, in NGI (and, indeed, also today) users' devices at the edge of the network are extremely powerful and would be able to generate their own local networking environments on-demand, without necessarily (or exclusively) relying on Internet functionality provided by core infrastructures. NGI needs to embrace (mobile) edge devices as "first-class network nodes", and support design paradigms whereby the control over the deployment and operations of network functions may also be allocated to users' devices, which autonomously decide how to cooperate with the core network to obtain the networking services they need at a certain point in time. In a rudimentary stage, this is the vision at the basis of including D2D communications in the standards of last-generation cellular technologies, as a way to support Proximity-based services, ProSe [1].

As a key effect of these emerging trends, humans are more and more placed at the centre of the technical systems they use and have an active role in their operations. Humans and the Internet devices through which they communicate become actors of a complex socio-technical ecosystem. One of the most intriguing effects of this convergence is that the *human becomes the centre of Internet systems* and, for this reason, in [19] this paradigm change has been termed an "Anti-Copernican Revolution".

NGI is bound to embrace and support this trend in the future. Indeed, we argue that NGI needs to take into consideration the human behaviour as a *structural design paradigm*, rather than as an afterthought. In this view, the human behaviour is not only considered at the services and application layers, according to conventional user-centric designs. It permeates the entire NGI "network stack" (although the concept of protocol stack itself would need to be re-thought), as people are not anymore mere users of network technologies and services designed exclusively with engineering optimisation parameters in mind, but their behaviour becomes one of the key elements for designing all facets of the Internet technologies.

We term this research approach *Internet of People*, and consider it as a key element for designing a truly human-centric NGI.

B. IoP: an inter-disciplinary research approach

IoP will be an inter-disciplinary research field. The IoP network systems will be desgined taking into account several interacting dimensions, such as: ICT, social sciences, cognitive psychology, complex networks, and micro-economics. This ecosystem perspective links our traditional technology-oriented perspective closely to social, economic and cognitive sciences (describing the behaviour of humans) for designing the networking and data exchange mechanisms of NGI.

ICT enabling technologies (both wired and wireless) provide the basic primitives for communication to occur. However, the algorithms and protocols for IoP networking and data exchange are not driven exclusively by the need to optimise network resource usage (as in the design of legacy Internet systems). In the converged cyber-physical environment, user devices become *proxies* of their users in the cyber world: they communicate, exchange and manage data on behalf of their users, and thus they should behave the way their human users would do if interacting with each other in the physical world. Here is where the other, "non-ICT" dimensions come into play.

Social sciences model the way users establish social relationships, how they trust each other, and how they are prepared to share resources with each other. NGI protocols exploiting these models (e.g., “social-aware networking protocols”) have proved to be very efficient in supporting communication in human-centred (mobile) social networks [4][11][16]. *Cognitive psychology* describes, among others, how human beings perceive and interact with data, how they assess relevance of information, how they exchange it when interacting, and how they extract knowledge out of it. Data-centric Internet systems for mobile networks have already been proposed, where these models are exploited to efficiently guide information diffusion among users [9]. Very useful models have been derived in the area of *complex network analysis* [6][21], describing, for example, human social relationships with compact graph descriptions, amenable to characterise human behavioural properties and exploit them in the design of networking solutions. *Micro-economics*, last not least, is modelling how humans negotiate the use of infrastructure and content resources, trade and share them. This is also fundamental knowledge to predict how they can interact with each other through NGI systems, and to embed such knowledge in the design of the corresponding protocols [12][15].

We would like to stress the fact that the proposed IoP approach to the design of NGI is not yet another bio-inspired networking design wave. Because of the fact that user devices act as proxies of their users, and the human brain is often the final destination of the information collected in the Internet, embedding efficient models of human behaviour in the core design of networking systems is a natural way to make devices behave as their human users would do if faced with the same choices and decisions. Moreover, this approach is not confined to designing human-centred applications. Instead, the inter-disciplinary approach of IoP impacts all conventional layers of the network stack above the enabling communication technologies, and brings advantage at all layers, as shown by the mentioned examples.

Adopting such an inter-disciplinary approach is not an easy task, as it requires to bridge very different scientific disciplines, which have not often collaborated with each other. We believe that a cornerstone to fruitfully follow this approach is seeking *quantitative* mathematical models (rather than qualitative descriptive models) or algorithimic definitions to describe the needed facets of the human behaviour [14][20]. Using quantitative approaches is fundamental, as it provides an appropriate common “language” that strongly supports and facilitates the discussion among diverse research communities. Ideally, these models and algorithms should emerge from the “non-ICT” community that studies that specific facet of the human behaviuor, as that is the research community that can truly challenge and validate these models. Once validated, being expressed in a mathematical and/or algorithmic form, the models are amenable to be directly “embedded” into NGI protocols and systems. Using this methodology, the models of the human behaviour are not interpretations given by Internet researchers of the human behaviour, but are rather well-established scientific descriptions, validated by the appropriate research communities. While these models will be developed and validated with an interdisciplinary work lead by non ICT communities, ICT technologies, like Big Data Analytics, will have a major role in the model design and validation [4].

This approach has been already used in some cases in the recent past (See Section II.D), proving to be a cornerstone of fruitful collaborations between heterogeneous research communities.

C. IoP paradigms for NGI

The IoP approach can be the basis for a seamless NGI ecosystem driven by Cyber-Physical Convergence, where networked entities can be humans, their personal devices, as well as other “machines” communicating in the cyber world. Specifically, we can foresee at least three corresponding classes of NGI networking paradigms:

- *The “Human proxy” paradigm*. This supports primarily networking between devices, whereby the users' personal devices communicate with each other acting as proxies of their human users. Personal devices may also communicate with “machines” (in the M2M sense), i.e., devices not bound to any specific users. In this case, personal devices would “proxy” the behavior of their users in interacting with the physical objects represented by these “machines”.
- *The “Crowdsourcing” paradigm.* This supports both device-to-device as well as on device-to-human and human-to-human interactions. The human user is perceived as another entity of the communication ecosystem, whose behavior can be modelled and predicted (clearly, up to a certain extent), whose resources can be shared and exploited to optimize the operations of the system. As a starting example, we may think of crowdsourcing systems, where humans are used to solve complex problems in a synergic way together with computers [5][22][23].
- *The “User experience” paradigm*. This is based on explicitly modelling the *reactions* that human users have to Internet services. This may range from simply modelling the quality of experience in using a given service, to more complex scenarios where the *actions* taken by the user in response to a certain level of the provided service and results in designing Internet systems modify the operation of the service itself or of correlated services [18].

D. Prior experiences

Initial results that, in retrospect, fall in the IoP vision have been obtained in recent EU projects. Hereafter, we briefly describe some examples.

- The FET HAGGLE and SOCIALNETS[1] projects developed the concept of *Electronic Social Networks*. In these projects, self-organizing mobile networks have been designed where the routing and data dissemination protocols embed models of the users social behavior. For example, models derived in the complex networks literature, describing the way social relationships drive

[1] http://www.social-nets.eu/

human movements, have been used to design efficient decentralized data dissemination protocols: whenever two nodes are close enough to communicate directly, content is exchanged between them based on the predicted movements of each one and the set of other nodes they are expected to meet, considering the set of social relationships of the users of the mobile nodes [7][24]. Or, the role of the users in their social environment (again, measured through complex networking indices) has been used as a routing metric to define self-organizing multi-hop routing schemes [11][16].

- The FET RECOGNITION[2] project developed autonomic data dissemination protocols exploiting *cognitive heuristics*, which are simple models of human brain functions. Unlike neural networks, cognitive heuristics do not reproduce detailed physiological structures of the brain. Rather, they model cognitive functions of the brain with simple algorithms that are particularly efficient to execute. The key feature of these algorithms is to reproduce heuristic behaviors of human cognition, i.e. the fact that the human brain takes decisions based on partial and possibly noisy information. Decisions are typically approximations of the best optimal choice, which could only be "computed" by acquiring and elaborating complete information about the problem, but spending many more cognitive resources. In RECOGNITION, a number of cognitive heuristics have been embedded into the decision process used by mobile nodes to decide which content to fetch from encountered nodes. In terms of performance, the resulting data distribution scheme has shown [9] to be as efficient as "conventional" mobile networking solutions, but much more efficient in terms of nodes and network resource usage.
- One of the activities of the FIRE EINS[3] (Internet Science) NoE explored the interplay between human social structures and information diffusion in Online Social Networks (OSNs). This is currently followed up in the H2020 SoBigData[4] Research Infrastructure. Among other results, it has been shown that microscopic structures of human social networks (specifically, the structure of the *ego network* between each user and its direct social peers) strongly impacts on the shape of information cascades (the set of nodes "covered" by information generated at a given node) [2] and on the paths taken by pieces of content that require a significant level of trust to be propagated [3]. This is one of the basis to design advanced information-centric services based on OSN platforms, and, more in general, to build NGI trusted decentralized data-centric network functions.

III. RESEARCH CHALLENGES

While promising, results mentioned in Section II.D are specific results that fall under the IoP general idea, but are far from exhaust the breath of the research challenges of this new paradigm. We believe that IoP, in the context of NGI, is a very promising concept that can generate extremely challenging and interesting research directions.

We can identify a first set of challenges, which deal with architectural aspects and definitions of protocols for NGI. Specifically:

- *NGI architectures based on IoP protocols*. NGI will possibly need to drastically re-think the current Internet architecture, in particularly NGI as a network primarily designed for humans, and for "naturally" supporting their behavior in the physical world. What is a correct architectural approach to embed human behavioral models in NGI protocols? Is the current separation of functions across the Internet stack still meaningful for NGI? How do we modularize functions into layers and stacks, and how do we deal with cross-layer information and interactions?
- *Social/Cognitive "overlays" beyond the mobile edge*. While it is clear that embedding social and cognitive models is beneficial for self-organizing networks formed by mobile users' personal devices, it is less straightforward how to exploit the same approach for services that also include core infrastructure and are deployed at the level of the entire network. In other words, is the IoP approach sensible only for supporting "small clouds" of mobile devices at the edge of the network, or can it permeate more broadly NGI, by also impacting in the way some core network functions are deployed and operated?
- *IoP data-centric NGI*. Most likely, data management will be one of the key functions that NGI will have to support as a network primitive, the same way the today's Internet natively supports multi-hop routing and forwarding. How should network-wide, *data-centric* NGI services be designed to take advantage the IoP concepts?
- *In-network service provisioning through IoP*. Beyond being content oriented, we may also envisage that NGI should also provide *computing* services on the available data as key native functions. IoP concepts can clearly be exploited also to perform computation on data (e.g., extracting knowledge from raw data), but what is the right approach to embed such functions in NGI primitives?

Finally, we mention a second set of challenges that are orthogonal to the ones described so far, and that address more foundational questions for an IoP-based NGI.

- *Resources management*. IoP will be built on a heterogeneous set of resources, provided by devices owned by specific users, devices not bound to any specific user, and human users themselves. What is the correct approach to represent these resources, advertise and orchestrate them, and make them available in the overall NGI ecosystem to build complex network functions?

[2] http://users.cs.cf.ac.uk/Recognition.Project/wordpress/
[3] http://www.internet-science.eu/
[4] http://www.sobigdata.eu/

- *Trust models*. In IoP network resources may be very dynamic and heterogeneous, and only partly controlled by (more or less) trusted operators. On the other hand, it will be in the interest of all users that IoP is an ecosystem where own resources can be shared in a fair way, in return of better network services built thanks to these shared pools of resources. In this perspective, which models should NGI adopt to establish trust and facilitate cooperation between parties, such that users will be confident in sharing and using each other resources?
- *Multiple facets of cognition*. Embedding human cognitive models has proved to be very helpful to design IoP data management solutions. This approach has the potential to become a core feature of an NGI based on the IoP concept. However, the approach explored so far (cognitive heuristics) is only one of the many ways how human cognitive functions can be modelled. Sometimes such modeling approaches are even contradicting with each other (e.g., cognitive heuristics vs. Bayesian approaches), and therefore it is not yet clear how to build a comprehensive representation of human cognitive processes, which could be used as a foundational component of IoP solutions.

REFERENCES

[1] 3GPP TS 23.303 “Proximity-based services (ProSe)”, https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=840

[2] Valerio Arnaboldi, Marco Conti, Massimiliano La Gala, Andrea Passarella, Fabio Pezzoni, “Ego Network Structure in Online Social Networks and its Impact on Information Diffusion”, *Elsevier Computer Communications*, Volume 76, 15 February 2016.

[3] Valerio Arnaboldi, Massimiliano La Gala, Andrea Passarella, and Marco Conti, “Information diffusion in distributed OSN: The impact of trusted relationships”, *Springer Peer-to-Peer Network Architectures*, Volume 9, Issue 6, pp 1195–1208, November 2016.

[4] V. Arnaboldi, A. Passarella, M. Conti, R.I.M. Dunbar, “Online Social Networks: Human Cognitive Constraints in Facebook and Twitter Personal Graphs”, Elsevier, October 2015.

[5] Ricardo Baeza-Yates. 2014. The wisdom of ad-hoc crowds. In *Proceedings of the 25th ACM conference on Hypertext and social media* (HT '14). ACM, New York, NY, USA, 1-2.

[6] Alessandro Bessi, Fabio Petroni, Michela Del Vicario, Fabiana Zollo, Aris Anagnostopoulos, Antonio Scala, Guido Caldarelli, Walter Quattrociocchi: Viral Misinformation: The Role of Homophily and Polarization. WWW (Companion Volume) 2015: 355-356

[7] Chiara Boldrini, Marco Conti and Andrea Passarella, “Design and performance evaluation of ContentPlace, a social-aware data dissemination system for opportunistic networks. *Computer Networks*, 54(4):589-604 , 2010.

[8] Cisco, “Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update 2015–2020,” Cisco, Tech. Rep., http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/mobile-white-paper-c11-520862.html, 2016.

[9] M. Conti, M. Mordacchini, and A. Passarella, “Design and performance evaluation of data dissemination systems for opportunistic networks based on cognitive heuristics,” ACM Trans. Auton. Adapt. Syst., vol. 8, no. 3, pp. 12:1–12:32, 2013.

[10] M. Conti, S. K. Das, C. Bisdikian, M. Kumar, L. M. Ni, A. Passarella, G. Roussos, G. Troster, G. Tsudik, and F. Zambonelli, “Looking ahead in pervasive computing: Challenges and opportunities in the era of cyber–physical convergence,” Pervasive and Mobile Computing, vol. 8, no. 1, pp. 2–21, 2012

[11] E. Daly and M. Haahr, “Social network analysis for information flow in disconnected Delay-Tolerant MANETs,” IEEE Trans. Mobile Comput., vol. 8, no. 5, pp. 606–621, May. 2009.

[12] H Fehr-Duda, E Fehr, “Sustainability: Game human nature”, Nature 530 (7591), 413-415, 2016

[13] Fernando, N., Loke, S.W., Rahayu, W.: Mobile cloud computing: A survey. Future Generation Computer Systems 29(1), 84 { 106 (2013)

[14] Gigerenzer, G., Hertwig, R., & Pachur, T. (Eds.). (2011). *Heuristics: The foundations of adaptive behavior*. New York: Oxford University Press.

[15] G Hein, Y Morishima, S Leiberg, S Sul, E Fehr, “The brain’s functional network architecture reveals human motives”, Science 351 (6277), 1074-1078, 2016

[16] P. Hui, J. Crowcroft, and E. Yoneki, “Bubble rap: Social-based forwarding in delay tolerant networks,” IEEE Trans. Mobile Comput., vol. 10, no. 11, pp. 1576–1589, Nov. 2011.

[17] A. Manzalini and N. Crespi, "An edge operating system enabling anything-as -a-service," in *IEEE Communications Magazine*, vol. 54, no. 3, pp. 62-67, March 2016. doi: 10.1109/MCOM.2016.7432173

[18] Peter Reichl, Sebastian Egger, Sebastian Möller, Kalevi Kilkki, Markus Fiedler, Tobias Hoßfeld, Christos Tsiaras, Alemnew Asrese: Towards a comprehensive framework for QOE and user behavior modelling. QoMEX 2015: 1-6

[19] P. Reichl, “From QoS to QoE: Buzzword Issue or Anti-Copernican Revolution?” Keynote abstract, EuroNF Workshop on Traffic Management and Traffic Engineering for the Future Internet, Dec. 2009.

[20] Roberts, S. G. B. & Dunbar, R. I. M. (2011). Communication in social networks: Effects of kinship, network size and emotional closeness. *Personal Relationships*, *18*, 439-452.

[21] E. Shmueli, V. K. Singh, B. Lepri and A. Pentland, "Sensing, Understanding, and Shaping Social Behavior," in *IEEE Transactions on Computational Social Systems*, vol. 1, no. 1, pp. 22-34, March 2014. doi: 10.1109/TCSS.2014.2307438

[22] O. Scekic *et al*., "SmartSociety -- A Platform for Collaborative People-Machine Computation," *2015 IEEE 8th International Conference on Service-Oriented Computing and Applications (SOCA)*, Rome, 2015, pp. 147-154.

[23] Roger M. Whitaker, Martin J. Chorley, Stuart M. Allen: New Frontiers for Crowdsourcing: The Extended Mind. HICSS 2015: 1635-1644

[24] Eiko Yoneki, Pan Hui, Shu Yan Chan, Jon Crowcroft: A socio-aware overlay for publish/subscribe communication in delay tolerant networks. MSWiM 2007: 225-234