Applications of Temporal Random Walks over Opportunistic Networks*

Victor Ramiro†, Emmanuel Lochin, Patrick Sénac

Delay tolerant networks (DTNs) were introduced [1, 2, 3] to deal with environments where interruptions or disruptions of service were expected. Such networks usually lack of end-to-end paths or any infrastructure to help communications. Usually, there is neither guarantee about the availability of the connections nor the topology of the network. Opportunistic networks are a special case of DTN that exploit systematically the mobility of nodes. When nodes contacts occur, routing protocols can exploit them to forward messages. In the absence of stable end-to-end paths, spatio-temporal paths are created opportunistically. Opportunistic networks are suitable for communications in pervasive environments that are saturated by other devices. The ability to self-organize using the local interactions among nodes, added to mobility, leads to a shift from legacy packet-based communications towards a message-based communication paradigm. Opportunistic networks can be associated with human networks where people are moving around. In this work, we study the use of Temporal Random Walks (TRW) as a simple method that can adapt itself to the selforganizing evolution of opportunistic networks.

Opportunistic networks can be crucial to provide solutions that scale to the future demands of mobile networking. For instance, The introduction of a new mobile infrastructure as TRW may help to resolve current problems on Network Offloading [4, 5, 6]. Natural disasters such as earthquakes, hurricanes and forest fires, can have a huge impact on the way people communicate [7]. The deployment of a self-managed opportunistic networks as TRW may help to improve communications in disaster or censorship scenarios. Mobile crowdsourcing systems (MCS) [8, 9, 10] are usually employed for these scenarios. TRW as an opportunistic crowdsourcing architecture able to do both: gather data among peers and distribute a filtered and global approximation for the measures.

This work is focused on the so called opportunistic networks. In these networks, mobile nodes may interact using their contacts as a communication opportunity. The store-carry-forward paradigm allows nodes to exploit spatiotemporal paths created by contact opportunities in order to deliver messages over time. Such routing mechanism usually provides some kind of message replication in order to increase the probability of message delivery. Instead we raise the question: *can we design a mobile and opportunistic infrastructure that could help deliver messages?* In the quest to provide such infrastructure, we study the application of temporal random walks (TRW) over the opportunistic networks. We base this idea on the following analogy: in a gathering of people without Internet connectivity, a simple way to share a piece of content is to pass a USB key. Each participant can add new information or a message when he or she receives the key. The same principle can be used as a publish/subscribe medium where everybody will get a copy of one specific message. Each person using the key can pass it to another nearby random person. This is

*Accepted at *Complex Networks 2016*

†Corresponding Author: victor.ramiro@isae.fr

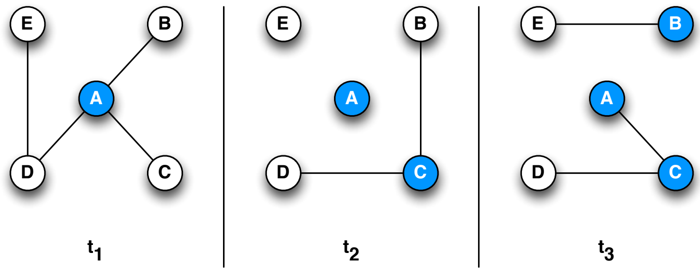

Figure 1: Dynamics of temporal random walks

the basis of a random walk where the network topology is changing according to the opportunistic contacts between participants. We explore the application and impact of TRW as a minimal and non invasive infrastructure from two points of view: data forwarding and data recollection.

The major contribution of this work is the introduction of a mobile lightweight communication infrastructure that emerges from the behavior of the opportunistic network itself. We propose the use of "Temporal random walks" (TRWs) to provide such self-infrastructure. The TRW architecture is basically a random walk in a temporal network that is exploited as a communication method.

For instance, in Figure 1 we see that at time t_1 A is selected as the starting node. At this time, A is connected with $\{B, C, D\}$. C is randomly selected with 1/3 probability. Then at time t_2 the connections have changed. We can see that C is connected with $\{B, D\}$. In this case B is selected randomly with 1/2 probability. Finally, at time t_3 E is selected as the only connected node. We see that the token is passed among nodes in the following contact sequence: $\{A \xrightarrow{t_1} C, C \xrightarrow{t_2} B, B \xrightarrow{t_3} E\}$ and hence the TRW mapping will be $trw = \{((w, t_1), A), ((w, t_2), C), ((w, t_3), B)\}$. We notice two things: *(i)* the degree of a node changes with time ($\delta_A(t_1) = 3, \delta_A(t_2) = 0, \delta_A(t_3) = 1$), hence the selection probabilities change, and *(ii)* in the temporal random walk we can profit from temporal paths that are created with the evolution of the communication: the path between A and E only exists thanks to other nodes' contacts.

Since the token passing in TRW is defined as an atomic operation, we can see it as the forwarding of one simple message among nodes. Hence,to evaluate the performance of our approach, we study the buffer occupancy of simple message forwarding. We focus on the drop ratio for message forwarding considering finite buffers by modeling message drops with a continuous time Markov chain (CTMC). We address the worst case scenario created by one-packet buffers for message forwarding in homogeneous intercontact times (ICT). We then explore the idea of token-sharing as a routing mechanism. Instead of using contacts as mere opportunities to transfer messages, we use them to pass the token over time. The evolution of the token is ruled by the TRW process. Sending a message is equivalent to copying it into the token. Eventually the destination node will get the token and all its addressed messages. We study the delivery effectiveness of such approach.

Finally, we study how to apply the TRW in order to monitor opportunistic networks. Compared to wired networks, opportunistic networks are challenging to monitor due to their lack of infrastructure and the absence of predictable endto-end paths. We present the feasibility, limits and convergence of monitoring such networks. More specifically, we focus on the efficient monitoring of the ICT between participating nodes.

References

[1] A. McMahon and S. Farrell, "Delay- and disruption-tolerant networking," *IEEE Internet Computing*, vol. 13, no. 6, pp. 82–87, 2009.

[2] A. Hooke, "The interplanetary internet," *Commun. ACM*, vol. 44, pp. 38–40, Sept. 2001.

[3] K. Fall, "A delay-tolerant network architecture for challenged internets," in *Proceedings of the 2003 Conference on Applications, Technologies, Architectures, and Protocols for Computer Communications*, SIGCOMM '03, (New York, NY, USA), pp. 27–34, ACM, 2003.

[4] B. Han, P. Hui, V. Kumar, M. Marathe, J. Shao, and A. Srinivasan, "Mobile data offloading through opportunistic communications and social participation," *Mobile Computing, IEEE Transactions on*, vol. 11, pp. 821–834, May 2012.

[5] P. Baier, F. Dürr, and K. Rothermel, "TOMP: Opportunistic Traffic Offloading Using Movement Predictions," in *Proceedings of the 37th IEEE Conference on Local Computer Networks (LCN)*, (Clearwater), pp. 1–8, IEEE Computer Society, Oktober 2012.

[6] F. Rebecchi, M. Dias de Amorim, V. Conan, A. Passarella, R. Bruno, and M. Conti, "Data offloading techniques in cellular networks: A survey," *Communications Surveys Tutorials, IEEE*, vol. 17, pp. 580–603, Secondquarter 2015.

[7] V. Ramiro, J. Piquer, T. Barros, and P. Sepúlveda, "The Chilean Internet: Did it survive the earthquake?," in *WIT Transactions on State of the Art in Science and Engineering* (L. A. Cardenas, ed.), vol. 1, pp. 133–151, WIT Press, 1 ed., Oct. 2012.

[8] Wazir Zada Khan, Yang Xiang, Mohammed Y Aalsalem, and Quratulain Arshad, "Mobile Phone Sensing Systems: A Survey," 2013.

[9] M. Conti, S. Giordano, M. May, and A. Passarella, "From opportunistic networks to opportunistic computing," *IEEE Communications Magazine*, vol. 48, pp. 126–139, Sept. 2010.

[10] R. Ganti, F. Ye, and H. Lei, "Mobile crowdsensing: current state and future challenges," *IEEE Communications Magazine*, vol. 49, pp. 32–39, Nov. 2011.