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***Abstract*—Opportunistic networking is rising due to the capability of end-to-end devices to exchange data directly, based on physical proximity as well as based on encounters of the persons carrying such devices around. The development of opportunistic solutions is often based on short-range wireless technology such as Bluetooth, and most of the times is validated via simulators or emulators. Today, devices are enabled not only with Bluetooth, but also with Wi-Fi Direct. Opportunistic networking solutions can therefore take into consideration these aspects (proximity among users and their encounter), to provide support to intermittent internet access as well as to assist traffic locality. This abstract describes the NDN framework for Opportunistic Networks (NDN-Opp), which is being developed aiming to support opportunistic forwarding based on users' interests and their dynamic social behavior.**

***Index Terms*—Named-Data Networking; Opportunistic data transmission; Social-aware routing; Wireless**

I. Introduction

In the context of wireless technologies as complementary support to existing access technologies (e.g., 3GPP, fixed networks) the most recent evolution standards reinforce the relevancy of *Device-to-Device (D2D) communication*. For instance, in LTE, D2D communication and the need to address the mentioned challenges that D2D faces, from a network operational perspective, are being worked upon. Then, in most Android smartphones today there is capability to rely on Wi-Fi Direct to support opportunistic data communication.

Wireless architectures have therefore been evolving from the initial centralized infrastructure mode to more complex, multi-hop paradigms, facing requirements such as the need to adjust to frequent movement, energy constraints, or even low-resource node architectures. Therefore, one of the main challenges of direct communication relates to the capability of its networking architecture to adequately operate in large-scale dense scenarios as they have a tendency to grow beyond the operator control [1], thus negatively impacting network operation aspects such as mobility management, spectrum usage, energy efficiency, or routing.

Generally speaking, these environments are crowded with devices that access the Internet often simultaneously: most, if not all devices, are capable of interconnecting and locally exchanging data, thus assisting in better offloading. While such capability exists, the networking design still considers data transmission across the access network, resulting in large traffic volumes impacting both the network operation, as well as pricing models [2]. Beyond conventional access networks, which are in their majority complemented with Wireless Fidelity (Wi-Fi), direct device communication is expected to keep on rising and to be held responsible for a significant amount of mobile traffic in the upcoming years.

In this context, a first challenge to address is the integration of opportunistic tools with the capability of direct communication, and to exploit such tools in the context of the user's daily routine. From a networking perspective, such tools are relevant to assist in keeping traffic local as well as in supporting communication without internet access. From a social perspective, these tools can be relevant by assisting users in the context of their daily routines. For instance, exploiting the physical proximity of users that share interests, to stimulate social interaction. A second challenging aspect for opportunistic networking tools relates with the potential optimization of the network access (by keeping whenever feasible traffic local) and therefore, to assist in developing new pricing models.

Due to the increasing capability of personal devices, opportunistic networking is gaining ground as it allows exploring data transmission with intermittent Internet access. This ever-growing interest on this networking paradigm is backed up by the different opportunistic routing solutions that have emerged throughout the years, ranging from simple epidemic approaches to more elaborate ones relying on social awareness (e.g., common affiliation/community, shared interests, levels of social proximity) [3]. In terms of the different opportunistic routing approaches, *social-aware* solutions have shown great potential given their more conservative approach to data transmission, and lower impact in terms of data replication. Current social-aware solutions rely on the interpretation that the computer science community has been doing from social sciences' theories. For instance, some approaches assume that devices whose carriers share affiliation tend to meet more often (Label [4]); high centrality nodes connect different clusters and these clusters are formed based on common neighbors (SimBet [5]); users with common interests tend to meet with each other more often than with other users (SocialCast [6]); contact duration and frequency are proper indicators to identify communities (Bubble Rap [7]); popular nodes, meeting many different others, have high delivery capability (PeopleRank [8]); time nodes spend together is a good indication of social interaction (dLife [9]); nodes with similar profile have high probability to meet one another (CiPRO [10]); nodes with similar interests make good next-hops for message delivery (SCORP [11]).

A significant weakness of current opportunistic solutions is the fact that their usefulness in realistic environments is not clear, as they have been extensively evaluated only through simulators and emulators. In summary, social-aware routing has shown great potential, but the impact of the considered social similarity assumptions is yet to be assessed in real-world deployment.

On the other hand, most opportunistic networking solutions rely on a host centric approach, transmitting packets between nodes regardless of the data being exchanged. In contrast, information centric networks allow the network to gain a better understanding of the data itself, enabling it to be easily cached and reused. Such support offers a huge potential in disrupted environments that rarely allow two hosts to reach each other. In order to provide support for a data-centric opportunistic networking approach, we make use of the Named-Data Networking (NDN) architecture.

In this abstract we provide an initial description of the NDN framework for Opportunistic Networks (NDN-Opp), which is being developed aiming to support opportunistic forwarding based on users' interests and their dynamic social behavior. The NDN-Opp framework includes some changes in relation to NDN in order to enable social-based information-centric routing over dynamic wireless networks. The development of NDN-Opp is based on SOCIOv1.0[1], is being developed in Java for Android. In order to evaluate the feasibility of using social-aware routing metrics we started by implementing an opportunistic routing based the Time-Evolving Contact Duration algorithm [12] used by the dLife protocol [9]. Nevertheless, NDN-Opp is been devised in a modular way to allow an easy integration of different opportunistic routing strategies.

II. NDN-Opp Architecture

The current specification of NDN-Opp aims to handle the dynamics of opportunistic wireless networks by forwarding interest packets towards best neighbors, which are selected based on their probability to deliver packets to a node carrying the interested data. This means that the current specification of NDN-Opp makes use of: i) the existing best route forwarding strategy to deliver interest packets, in which case the cost is related to the social weight computed by the social proximity module: ii) the NDN "breadcrumb" approach to deliver data packets based on the information stored on the PIT.

The cost of each name prefix (stored in the FIB) is the value of the social weight compute for the best next hop, as computed by the social proximity module. NDN-Opp provides support to the NDN natural pull communication model (e.g. data sharing applications, such as the Now@ app being developed at COPELABS) and to the push communication model used by interactive applications, such as the short message application, Oi!, initially developed to evaluate the opportunistic operation of NDN-Opp:

- Support to pull model: NDN-Opp allows a receiver to express its interest in receiving some type of data, by sending Interest packets to name prefixes such as /app/Now@/Topic used by the Now@ application (data sharing application being developed to demonstrate NDN-Opp support to pull communication models).
- Support to push model: NDN-Opp allows a node to express its interest in receiving data from a specific application (name prefix). For instance, if a node Nx would like to start using the short messaging application, Oi!, it send an Interest packet with name prefix /app/oi!/Nx/ or of type /app/oi!/Nx/Ny if node Nx would like to receive Oi! short messages only from node Ny. To support the pull model, NDN-Opp included the concept of Long Lived Interests, allowing one Interest to serve more then one data packet.

In order to handle the intermittent nature of the wireless links, the NDN-Opp includes the concept of virtual faces, which send and receive packet via a Wi-Fi direct link. Each virtual face can be in two states (ON and OFF), and is named after the identified of the neighbor node. Since packets may not be handle to be dispatched after a SendInterest or SendData issued by the forwarder, each virtual face implements two queues: i) an Interest Queue (IQ), which stores Interest packets to be sent; ii) a Data Queue (DQ), which stores pointers to the Data block (hold in the Content Store) to be send. The NDN face management creates virtual faces after the first contact with a new neighbor node.

In summary, NDN-Opp encompasses the following novel contributions to the NDN framework in order to allow its operation over opportunistic networks:

- Novel social-aware routing engine, able to implement different algorithms able to select best routes based on the social weights computed from a social proximity module.
- Novel forwarder able to support opportunistic communications.
- Integrates the concept of Long Lived Interest in order to support push communication model, as well as to reduce traffic in opportunistic networking scenarios.
  - Users manifest their interest in getting data from some type of application (e.g. short messaging) or from some specific node.
  - Interests persist in the network for as long as established by the Interest source by setting a Long Lived Interest parameter.
  - While Interests persist in the network, data can flow towards the established intermittent path.
- Integrates the concept of virtual intermittent face, which can be in two states (ON/OFF). Virtual interfaces include queues of interests and data, aiming to speed up transmission over short-lived wireless links.

[1] Available at: https://play.google.com/store/apps/details?id=com.copelabs.oiframework

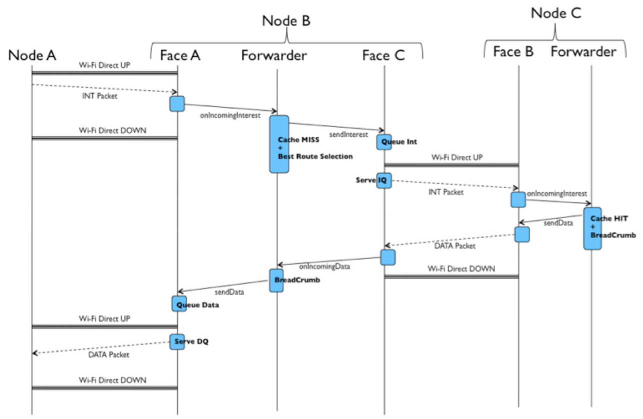

Figure 1. Illustration of NDN-Opp operation.

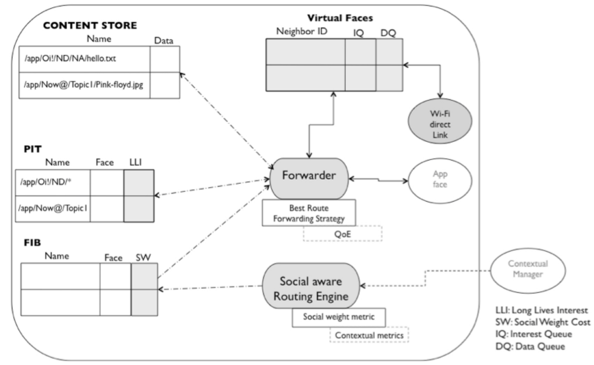

Figure 2. NDN-Opp design.

- Makes use of: i) best route forwarding strategy to handle Interest packets based on social weights; ii) the default "breadcrumb" approach to forward data.
- Two new fields in the PIT and FIB: Social Weights in the FIB; Long Lived Interest (TTL) in the PIT.
- Novel Wi-Fi direct.

The operation of an NDN-Opp node, as illustrated in Fig. 1, goes over a main set of operations when it gets in contact with another mobile NDN-Opp node (e.g. when a virtual face goes UP). As shown Fig. 1 the operation of an NDN-Opp node is similar to the basic NDN operation: the node state is changed by the arrival of an Interest or a Data packet.

The major constraint of the NDN operation over opportunistic networks is the intermittent nature of wireless connectivity. In order to accommodate this property of wireless links, virtual faces are used. In this case, each mobile node has a virtual face towards to each encountered node (e.g. Face A and C in the case of Node B in Fig.1). Each virtual interface implements an Interest Queue (IQ) and a Data Queue (DQ), as shows in Fig 2.

This means that in NDN-Opp the existing of virtual faces creates an indirection: The normal operation of NDN finishes with a packet being send through a face; with NDN-Opp the packet handling operations end with the packet being stored in the respective queue of the selected virtual interface. Packets are transmitted by serving the interest and data queues of the virtual face that got active. Fig. 2 shows the current design of the NDN-Opp based on a novel forwarder and routing engine.

The **forwarder** is able to send and receive packet from several virtual faces, as well as the application face. Upon the reception of an Interest packet, the normal NDN state machine is used, but the PIT will store also the information related to the duration of the Interest (LLI). To forward Interest packets, the best route forwarding strategy is used, in which the FIB stores the cost associated to each name prefix (the cost is computed by the routing engine). When a data packet arrives, the normal operation occurs, being the output virtual face selected based on the information stored in the PIT.

The **social-aware routing engine** is responsible to select the best neighbor to reach data related to a certain name prefix. For this propose the routing engine can run any type of social-aware opportunistic routing algorithm. The first algorithm used by NDN-Opp is the Time-Evolving Contact Duration approach (TECD) [12] used by the dLife and SCORP protocols [9], [11].

Computing routing information in opportunistic network based on social interactions has great potential as less volatile proximity graphs are created. We believe that the accuracy level of social interactions is mainly dependent on the statistical duration of contacts over different periods of time, since people have daily habits that lead to a periodic repetition of behavior, and will more accurately reflects the real evolution of social ties than relying solely on the contact between nodes or well-defined social structures.

The TECD algorithm aims to compute the Social Weight (SW) of a node towards a name prefix (which can represent another node, such as used by short messaging applications). By computing SWs, the TECD algorithm is able of capturing the evolution of social interactions in the same daily period of time over consecutive days, by computing social strength based on the average duration of contacts. The TECD algorithm can also be used to capture the Importance of any node (TECDi) in a daily sample, based on its social strength towards each user that belongs to its neighbor set in that time interval, in addition to the importance of such neighbors. The TECDi is based on the PeopleRank function [8]. However, TECDi considers the social strength between a user and its neighbors encountered within a daily sample, while PeopleRank computes the importance considering all neighbors of that node at any time.

The social-aware routing engine is responsible for the computation of social weights based on information collected about neighbor devices. For that the routing engine makes use of an interface towards a Contextual Manager.

It is expected the Contextual Manager to be able to provide information about neighbor devices, in order to ensure the proper operation of the routing engine. The basic operation of the NDN-Opp routing engine requires information about the average contact duration between pair of nodes in specific daily samples, as illustrated in Fig 3.

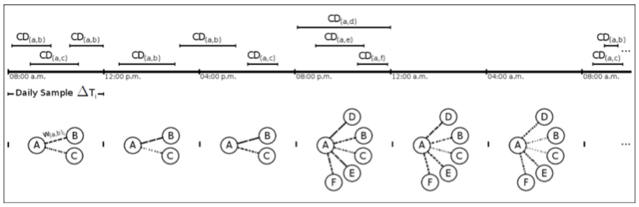

Figure 3. Contacts a node A has with a set of nodes x in different daily samples.

The operation of the social-aware routing engine is based on a social weight measurer, a social weight repository and a gatherer of information about social weight and data carried by neighbor nodes:

- Social Weight Measurer (SWM) – responsible for keeping track of the contact duration information provided by the Contextual Manager. SWM maps this duration to the name prefixes carried by the encountered nodes. Based on that, this component computes the level of social interaction of the current node towards the name prefixes carried by encountered peers. This social weight determines how good the encountered node is to reach nodes that carry data related to such name prefixes. The social weight computation takes place at every hour as to allow for a better view of the dynamic social behavior of users.
- Social Weight Repository (SWR) – responsible for storing the list of name prefixes that the current node comes across (obtained upon encountering a peer). SWR holds the name prefix, time it has been first encountered, and the cumulative duration of within a specific hour. In the case, the current node still 'sees' such name prefix (i.e., respective peer node is still in the vicinity), the time of first encounter is updated and contact duration is accounted by SWM for the new hour.
- Social Weight and Carried Data Gatherer (SWCDG) – responsible for obtaining the list of name prefixes and social weight towards them of encountered node. This element is also responsible for obtaining information concerning the content carried by encountered nodes.

The computation of social weights is triggered when a specific face notifies the SWM of the presence of a neighbor node. The SMW creates entries for this encountered node in the SWR considering the name prefix information obtained by the SWDCG. The SWM keeps track of the contact duration between current and encountered nodes by querying the Contextual Manager and updates the SWR accordingly. Since nodes (i.e., their users) present different patterns of behavior in different time periods, the computation of social weights takes place in an hourly fashion. Information obtained by the SWCDG from the encountered node is used to populate PIT and the content store.

III. Summary and Ongoing Work

This abstract provides an initial description of an opportunistic data communication framework, NDN-Opp, which aims to provide an extension of the NDN framework towards opportunistic wireless networks, which currently are being investigated based on a host-based networking concept.

NDN-OPP is been developed considering the levels of social engagement among users, and taking advantage of any contact opportunity between their devices by means of Wi-Fi Direct. Currently, NDN-Opp, which is based on SOCIOv1.0[2], is being developed in Java for Android. The goal is to be able to provide support to opportunistic communication in the named-data networking paradigm. Also, we intend to validate the performance of NDN-Opp i in terms of energy and processing efficiency, reliability and scalability in a larger-scale scenario (i.e., including a large number of devices to be carried by students at University Lusófona campus).

Ongoing work encompasses the exploitation of different contextual information provided by the Contextual Manager for the development of novel routing approaches. The major action points are:

- Interface with the Contextual Manager: The collection of context information about neighbor nodes, done currently by scanning the Bluetooth face, should be done also by scanning the WiFi direct face. The goal is to allow the collection of neighbor information to be done over the same wireless range as the one used to exchange data.
- Novel opportunistic routing mechanism. Currently NDN-Opp makes use of the social-aware algorithm used by existing routing approaches (dLife/SCORP) [9], [11]. We are investigating an alternative proposal for the NDN-Opp framework based on novel strategies to forwarding interest packets in dynamic networks. In a first stage we will keep using the NDN default "breadcrumb" strategy to forward data. In a second stage we will investigate a more intelligent method also to forward data, aiming to exploit any contact with a neighbor node able of forwarding data towards the receiver(s), and not just the wireless contact with the node that previously sent the Interest packet (which in the approach followed in the default NDN "breadcrumb" approach). The performance of both alternatives will be assessed in real scenarios.

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