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Adaptive Routing for Challenging Networks

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Index Terms— DTN, self-adaptive systems, routing, roles

I. MOTIVATION

DTN is a network technology that allows communication between devices in a network without end-to-end connectivity. DTN exploits the device's mobility to create a virtual communication channel used to either offload the Internet infrastructure [1], [2] or to overcome the limitations of the Internets' coverage [3]–[5]. Limited coverage can be caused by environmental, political or economic reasons. Environmental challenges are characterized by difficult access, e.g., deep seas, extra-terrestrial communication, accidental areas, disaster regions, etc. In war and conflict zones, it may not be possible to build the necessary infrastructure due to political reasons. Finally, the lack of coverage is also noticed in regions in which the installation of the Internet infrastructure has a low return on investment. This is frequently the case in underdeveloped countries and isolated regions, implying that the current lack of access to information is not a technological problem, but rather an economic one. This phenomenon is mentioned in literature as *Digital Divide* [6].

Routing in DTN is a challenging problem, due to possibly long delays, frequent network partitions and the lack of end-to-end connectivity. Many DTN routing protocols have been proposed during the last years, each of them showing superior performance for the specific use case they were proposed and evaluated for. However, the great majority of these protocols ignore the fact that the underlying network has a dynamic nature and its characteristics may change over time. External events (e.g., traffic jams, public protests) may disturb the mobility behavior of a network in which mobile devices move respecting a contact plan (i.e., deterministic DTN), causing contact delays, failures or influencing the quality of the communication channel. In such situations, the network may still behave predictably, even though its contact plan is not precisely respected. We are convinced that in such cases, utility-forwarding algorithms as Seek-and-Focus [7], PROPHET [8], MaxProp [9], etc. may achieve better metrics (e.g., delivery probability, delivery delay) than a deterministic algorithm such as Contact Graph Routing [10], as long as the network does not converge to its initial state. In the same way, external events (e.g., natural

catastrophes, accidents) may cause predictive networks to behave erratically.

Replication-based routing (e.g., Epidemic [11], Spray-and-Wait [12]) is the simplest routing approach in DTN, since it does not require metadata exchange among peers and propagate information epidemically (i.e., replicate message at each encounter). On the downside, they are prone to congestion and waste network resources [13]. Utility-based routing approaches are able to provide higher delivery under constrained resources and better resource utilization. They exchange metrics at contact opportunities and use them to choose the best candidates for bundle forwarding. Still, for highly predictive and deterministic networks, such algorithms still under-utilize network resources since they are not able to take channel capacity into account, and are more prone to congestion than deterministic routing. Some implementations of deterministic routing take capacity into consideration, but need detailed information about the network behavior given as input.

II. OBJECTIVES

We present a research project whose goal is to understand in which cases and to which extent context-based routing adaptation may improve the performance metrics (e.g., delivery probability, delivery delay, energy efficiency, etc.) in challenging networks. We focus on networks with predictive mobility patterns that might suffer from temporal interference. This overall goal can be subdivided into three parts.

First, devices within an adaptive network must be able to sense its surroundings and adapt its routing strategy based on information collected during contact opportunities. Information exchanged plays a crucial role since it is also needed for the forwarding decision and may affect the maximum acceptable network size. Therefore, the first question to be answered is: What type of information should be exchanged between devices? This is challenging since no device has real time information about the overall state of the network.

Second, we want to assess the performance difference in realistic use cases using adaptive routing. We are especially interested in finding out whether a network of devices using diverse routing strategies can outperform the best result of

the set of runs in which each routing strategy has been applied throughout all devices.

Finally, we want to find out common characteristics of good candidates for adaptive routing, so that the outcome of this work could be used to support other individuals to understand whether their use cases are good candidates for an adaptive approach.

III. METHODOLOGY

In order to achieve the goals, several challenges must be overcome. First, a set of metadata has to be selected and exchanged during contact opportunities based on the protocols that will be supported.

Second, DTN devices have to be able to sense and differentiate context to trigger routing adaptation. Our answer to this challenge is to define a set of metrics to be exchanged between communicating elements during contact opportunities transitively, providing every device an understanding of the whole network (context). Additionally, we will use simulation tools for Opportunistic networks (e.g., The-One [14], OMNet++ [15], OpenJump [16]) so as to create realistic scenarios with deterministic mobility that temporarily changes its behavior and verifies how suitable the devices to recognize context change are. Based on these simulations, we will have a general idea about the minimal network overhead caused by the information exchange.

Third, we plan to assess the performance of adaptive routing in realistic scenarios. This challenge can be further divided in: simulating realistic scenarios, providing mobility adaptation and performance assessment. Next, we will design a DTN adaptive routing framework based on current DTN implementations (e.g., DTN2 [17], ION [18], IBR-DTN [19] or uPCN [20]). Although queuing order and deletion policies may strongly influence the network performance [21], we plan to focus exclusively on the adaptation of the routing module. Regarding the adaptation mechanism, we plan to use the concept of roles [22] that allows to add or exchange dynamic behavior to an entity at runtime. Next, an implementation of the framework will realize the main concepts of the work.

Finally, in order to assess the performance of the implemented system, we plan to create a pure ad-hoc network (e.g., simulating the behavior of a Mars-hover network). The simulation of contacts can be done with docker [23] containers connected to a virtual switch (e.g., OVSwitch), using TCP or UDP as convergence layer for the bundle protocol. The contact plan can be passed to a SDN controller as POX [24] that changes the state of the switch ports. By default, messages between containers should be dropped, but pre-defined schedule messages at certain ports are accepted, simulating contact opportunities.

IV. RESEARCH PLAN

My work started with a literature research about the state of the art in DTN, including routing protocols, mobility

models and congestion control. As a next step, a CGR implementation was provided for opportunistic networks in The-One, based on an existing variant developed at the TU Dresden for satellite networks. In CGR, the topology is given as input and stored as a graph, in which the vertices represent contact opportunities. Based on this insight, the sensing algorithm runs on each node, stores information collected locally about its surroundings (e.g., buffer utilization, contact opportunities, traffic demand) and exchanges it transitively during the contact opportunities, allowing every device within the network to have an idea about the network behavior at run time. The novelty of this approach is that a device is able to exchange arbitrary information that later may be used to sense network changes.

We are researching about metadata exchanged in current dissemination algorithms in order to understand what is the minimal metadata set necessary to support an adaptive approach. Next, we plan to provide maps for The-One with real data from Open-Street maps to perform realistic traffic simulations. Run-time adaptation will be added to simulate scheduled (e.g., maintenance work) or non-scheduled (e.g., accidents) events. Still in 2019, the overhead caused by the information exchange and memory utilization should be assessed according to the network size.

In 2020, we will focus on the design, implementation and assessment of the framework. Some work has already been initiated, in pursuance of these goals: a simple variant [25] of LyRT [26] was implemented based on [26] to deepen my understanding of the concept of roles; we started a simulation tool for testing with OVSwitch to be used with our implementation [27]. A summary of the steps planned in our work can be found in the table below.

#	<i>working package</i>	<i>start</i>	<i>end</i>
1	Literature Research	Q2 2018	Q4 2018
2	Context Information Exchange	running	Q2 2019
3	Simulate Adaptive Scenarios	running	Q4 2019
4	Framework Design	running	Q1 2020
5	Framework Implementation	Q1 2019	Q2 2020
6	Assess Performance and Comparison	Q3 2020	Q3 2020
7	Characterization of good Candidates	Q3 2020	Q3 2020
8	Write Process	Q4 2020	Q1 2021

Table I
RESEARCH PLAN

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