An Opportunistic Connectivity Network for Rural Areas in Senegal

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Abstract. In this paper, we present an *opportunistic connectivity* approach to building a network for rural areas in Senegal. Our proposed solution is based on a simple principle: *given any situation, use the best connectivity solution available; and when no solution is available at the moment, use delay/intermittence tolerant solutions to offer "offline" services*. Our network is built using point-to-point Long Distance Wifi links which are used wherever available. If a LD-Wifi link is not available, we use SMS service as a support for data communication. In areas with no coverage, we use DTN (Delay Tolerant Networking) solutions. For the seamless integration of all these technologies, we implement our light-weight platform on NDN (Named Data Networking), a new architecture proposed for the future Internet. A low cost implementation of the solution has been deployed in a test environment using Raspberry Pis and GSM dongles.

Keywords: Rural network deployment · DTN · NDN · SMS
Long Distance Wifi

1 Introduction

In the last decade, Africa has witnessed an increasing rate of adoption of new technologies. In Senegal the penetration rate for mobile phones is 116.6% while that of Internet continues to increase at a 60.28% rate [1]. According to the WEF (World Economic Forum)'s "Network Readiness Index" ranking [2], Senegal is on the top list in West Africa and occupies the 14th place continent-wide. This leading position is partially due to the favorable geographic position of the country, which is a hub for many underwater cables [3] and serves as an interconnection point for its neighbors.

Despite the privileged geographic position and the many efforts by the public and private actors, there remains a lot to be done in terms of connectivity, as shown by a recent report from the government [1]. The three main cellular providers (Orange, Tigo and Expresso) offer 3G services but mostly in urban areas. 4G services have only recently been launched, only by Sonatel and only in major cities. ADSL services are still offered in a monopolized way and is almost inexistent in most of the country. The government's efforts to lay fiber has been very slow and to date, only 9000 km of fiber have been

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installed. In addition to that, the cost of connectivity remains relatively high [4]. Overall, a lot of effort needs to be made in terms of diversification of the services and the service providers, accessibility to connectivity and enhancement of current infrastructures as well as building new ones.

This need of infrastructure building is even more pronounced in rural areas, which have received a small portion or even none of recent investments. In fact, due to low density of population in these areas, private companies (and unfortunately government) focus their investments in urban areas, where returns in investment (RIO) are higher. This has led to a widening digital gap between rural and urban areas within the country and the many opportunities that can potentially be enabled by ICTs are yet to be fully witnessed by the countryside.

To address the lack of connectivity in rural areas, we propose a novel connectivity architecture that is based on a simple opportunistic principle: *given any situation, use the best connectivity solution available; and when no solution is available at the moment, use delay tolerant networking (DTN) principles to offer offline services*. Our network will be backboned using point-to-point Long Distance Wifi links [5]. On the access links, it uses data services wherever available. If none of the data services is available, we use SMS service as a support for data communication. In areas with no network coverage, we use DTN solutions [6]. For the seamless integration of these different technologies, we use the newly proposed “Named Data Networking” (NDN) architecture, which is found to be naturally suitable to environments where connectivity is intermittent.

The remaining parts of this paper is organized as follow. The next Sect. 2 presents a non-exhaustive list of works that are related to the present paper. In Sect. 3 we discuss the details of our proposed solution by focusing on NDN as well as our deployment test. Closing remarks and future are presented in Sect. 4.

2 Related Work

Developing rural connectivity networks has been a topic of widespread interest in the last decade. The World Bank has funded a couple of such projects [7]. Village Base Station (VBTS) [8] is another economical and optimized architecture for areas of low user density and limited infrastructure. It is a GSM base station designed to be deployed “off the grid” to locations without power or network infrastructure. It uses DTN principles, but mostly in order to optimize energy usage. There have been a lot of activities in the field of delay tolerant networking DTN: IBR-DTN [9] and ION- DTN [10] are open source implementations of DTN. ZebraNet [11] is an application of DTN for real biological. Although the application area is the same as ours, the technologies used in these projects are different from our NDN.

The work in [12] is the most related to ours. It applies the NDN paradigm into Vehicular Network (V-NDN) and implements an architecture that enables networking among computing devices independent from whether they are connected through wired infrastructure, ad-hoc, or DTN. An experiment was run in the campus of UCLA. Despite the difference in the targeted application, the paper shares many commonalities with our paper. One fundamental difference in our approaches is the opportunistic principle that guides our implementation, and which they do not consider (probably because of their focus on V-NET). Also, due to the characteristics of our application environment (rural), our paper is more focused on the DTN aspect of the network. Finally, [12] has not implemented our SMS features.

3 Opportunistic Connectivity

Rural areas are characterized by factors that are a-priori unfavorable to the development of new technologies. First, the areas are difficultly accessible because transportation infrastructures are often impractical or inexistent. This translates to high costs for building and maintenance of network infrastructures, which most of the private (or public) actors are not willing to bear. In addition, population are sparsely scattered over the areas with a very low density. As a consequence, covering the rural areas requires large scale deployment, while the expected RIO is quite low. Thus, any viable solution should have a relatively low building and maintenance cost.

Another characteristic of rural areas is that connectivity, if it exists, might be very intermittent because of many reasons. First, downtime periods tend to be longer in rural areas because of the lack of local expertise and appropriate transportation infrastructures. More seriously, grid power is inexistent or at the best unreliable. Also, renewable energy solutions are yet to be adopted in rural areas. As a consequence, network infrastructures, which highly rely on grid power, are subjects to the many ups and downs of the grid. Hence, a realistic approach to the problem of connectivity should assume that links will be up and down at a rate that is much higher than usual.

3.1 Our Three Pillar Technologies

Bearing this in mind, we propose an opportunistic connectivity architecture that combines different technologies as follows: *at any given time, uses the best communication solution available*. Our current implementation is built upon three main pillars: Long-Distance WIFI (LD-WIFI), SMS for Data (SMS4D), and Delay Tolerant Networking (DTN) principles by using moving entities as data mules.

LD-WIFI is a low cost solution that extends the IEEE 802.11 technology to kilometers while keeping the cheap hardware. It has been tested and deployed in many parts of the world [13]. It uses unlicensed band, has been implemented in open source and is today available online and off the shelves. In our project, we use LD- WIFI as backbone by building a set of point-to-point links.

SMS4D is an approach that uses the short messaging system as a support for data communication. For that, we first note that, because of its potentially low data rate, SMS4D will not be suitable certain applications such as live video. However, for applications that tolerate delay and are not data-greedy, SMS4D might be very suitable. In our current implementation we use GammuSMS Deamon [14] and a GSM dongle as a gateway. We buy prepaid cards from Orange (Sonatel) with a subscription that gives up to 200 sms a day and costs 1000FCFA (about $1.6).

Finally, there is exist situations where none of the technologies above is available. In these cases, we use DTN principles to continue the "communication" offline. For that, we rely on the mobility of (physical) agents such us human, vehicles and drones which can serve as carriers for the communication. In this work, we implement the DTN principle as a new forwarding strategy for NDN.

By combining different (and independent) communication infrastructures, our system gains in robustness. Moreover, with the implementation of the DTN principle, we provide connectivity to areas without network prior coverage. We discuss the details of our implementation in the next section.

3.2 Implementation Platform: Named Data Networking

Our proposed platform integrates the technologies mentioned above in a seamless manner by using the newly proposed "Named Data Networking" architecture which is found to be naturally suitable to environments where connectivity is intermittent.

NDN is an architecture in which data is requested by name rather than location. It is based on two main principles that are suitable for DTN: (1) *Interest* packets stay, up to a certain duration, in the Pending Interest Table (PIT) unless it is satisfied (2) *Data* packets are stored in the Content Store to enable caching feature. These behaviors match the requirements to build DTN as the request or the response can live in a disconnected node while waiting for active links to transmit the packets to the next hop. This makes NDN very appealing for communication in underserved areas.

In NDN, it is the forwarding strategy that determines when and where an *Interest* packet is transmitted. Existing forwarding strategies [15] focus of QoS and congestion control by assuming that the link layer is stable enough and direct links exist between the different nodes physically or over the air. That assumption is not true in underserved areas where connectivity might be intermittent for several reasons, as discussed above. As a consequence, supporting DTN requires a specific forwarding strategy that enhance the opportunistic aspect of NDN data transmission.

We implement a DTN forwarding strategy based on the follow principles: First, as the data may stay in a transit node for a long duration, the strategy ensures that the *interest* packet stays active in the PIT until it is satisfied. Second, the DTN strategy plays a proactive role to identify the forwarding opportunities each time that a link is detect for a new hop. Moreover, the strategy handles the priorities for different layer 2 technologies. It may use SMS to transmit a packet if no Wifi link is available and no mule shows up for a certain duration. Figure 1 gives a sketch of our DTN strategy.

DTN Forwarding Strategy (simplified):

1- *Receive(interest/data)*

2- ***If*** *Wifi interface is connected to next hop: send to next hop*

2- ***Else****:*

- ***If*** *SMS-Enabled-Appl: send to SMS gateway*
- ***Else****: keep in content store and forward upon data mule detection event*

Fig. 1. DTN strategy

NDN introduces a new paradigm for accessing content where content can be retrieved from the network caches instead of a systematic retrieval from the source. For rural areas connected using DTN, this feature is valuable as the content retrieved in a given area will stay in the caches available within this area and can be retrieved instantly by other users without a need for an active connection to the source. Moreover, if multiple users are requesting the same content within a short time interval, the requests will be aggregated which allows a natural optimization of the network usage. This built-in optimization is very important in the rural connectivity setting where it is expected that most links will be of low data rate (e.g., SMS4D links). In fact, in this case, having less traffic to carry inside the network is vital.

We implement our DTN forwarding strategy [16] and integrate it with the NFD (NDN Forwarding Deamon) [17], which we run on Raspberry Pi3's. We use the NDNCxx API [18] to develop our consumer and producer test applications. A proof-of-concept experiment was carried at the end of the month of January in the campus of the University Alioune Diop of Bambey.

3.3 Test Deployment

In our experiment we define three network elements: a producer generates random data (as in [18]), a consumer requests the data, and a mobile node (data mule) acts as relay or data mule (when suitable). All nodes are Wifi-capable R-Pi3's that run an implementation of our platform. The consumer and producer are equipped with GSM dongles. The consumer and one of the LD-Wifi radios are co-located at one building (Site A in Fig. 2). Three hundred meters away, sits the producer with the other LD- Wifi radio. The mobile node was handled by a pedestrian and was powered using a portable charger. It played the role of a data carrier in all our experiments.

Fig. 2. Opportunistic connectivity: proof-of-concept deployment

In our first experiment, we place the consumer and the mobile in the same network in Site A and connect it to Site B via LD-Wifi. In this setting, all tree nodes are in the same network and the mobile node is just a "relay". In the second experiment, we deactivate the Wifi interfaces and activate the SMS gateway. In this case, when the consumer sends a request, it realizes that the Wifi interface is down and directly uses the SMS to send the interest directly to the producer. The producer gets the request and responds also using SMS. In the last experiment, we deactivate the LD-Wifi and use a smartphone as (short range) Wifi hot spot. We first put all nodes in the same network and then move the producer to Site B, so that the Wifi interfaces are all up, but the producer is disconnected to the rest of the network. When the consumer generates the interest, it realizes that there is an interface to the next hop (the mobile node), to which it forwards the interest. Upon reception, the mobile finds that the interface is up, but there is no connection to the next hop (the producer). It then keeps the interest in its content store. From this point, the pedestrian starts walking towards Site B, having with him the Wifi hot spot and the mobile node. Since Site B is 300 m away, the consumer gets disconnected from the network at some point. Upon arrival, the producer detects the Wifi interface, reconnects to the mobile node to receive the interest and sends it the response. A similar process gets the data back to the consumer.

4 Conclusion and Future Work

In this paper we present a new architecture for rural connectivity. It is based on a simple opportunistic principle: *given any situation, use the best connectivity solution available; and when no solution is available at the moment, use delay/intermittent tolerant solutions to offer "offline" services.* We implement a version of our platform that builds on three pillars: LD-Wifi, SMS, and DTN principles. For a seamless integrations of these different technologies, we implement our lightweight solution on NDN. A proof-of-concept deployment has been carried using Raspberry Pi3 at the campus of the University Alioune Diop of Bambey. A larger scale deployment is being prepared with two use case applications: a rural online market platform and a system for environmental data collection. Such large scale deployment will also involve evaluating the performance of our system by studying metrics such as the size of the content store, the average time to get a response, the "optimal number" of data carriers, the data rate obtained with SMS4D etc. In this deployment, we also plan to integrate other communication technologies such as ZigBee and Bluetooth.

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