Delay Tolerant Networking for the Socio-Economic Development in Rural South Africa

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Abstract. Rural areas in economically developing regions often suffer from a slow and unreliable communication network infrastructure, which turns out to be a common bottleneck limiting access to content and services that promote economic growth. We report here how Delay Tolerant Networking (DTN) can serve micro-business opportunities in such challenged locations. A DTN field trial conducted in 2015 in rural South Africa is examined to evaluate DTN architectures to best enable content distribution in areas where affordable communication channels are not fully available. The use-case in the trial was the support of micro-entrepreneurs that had been given access to simple cinema-in-a-backpack kits (battery, mobile projector and WLAN connection, plus software) that opportunistically connect to a DTN in the area. The network enabled the micro-entrepreneurs to order, receive, and screen movies at locations in under-served regions and in addition to invent and to execute micro-business activities around the screenings. The digital content was distributed to the micro-entrepreneurs by means of a DTN network with mobile infostations (wireless DTN-enabled devices) mounted on public transportation vehicles (commuter buses). In this paper, we present a six-month long field deployment that was organized in partnership with local institutions. We discuss the technical implications and make recommendations to support a socio-economic development in the under-served regions of rural South Africa.

Keywords: Socio-economic development · Business models · Delay tolerant networks

1 Introduction

ICT is playing a significant role in achieving future sustainable development goals as the world moves faster and faster towards a digital society. ICT has been utilized in many recent economic development projects to improve the

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socio-economic status of rural populations in economically developing regions and drive economic development. The MOSAIC_2B project [11] aims to unleash opportunities for micro-entrepreneurs in rural areas of South Africa by providing them with entertainment and educational media content. Then these micro-entrepreneurs, equipped with a low-complexity cinema-in-a-backpack kit (see Fig. 1), can deliver educational and entertainment content in remote villages. We have designed the cinema-in-a-backpack kit that exploits the advantages of Delay Tolerant Networking [7] to create opportunities for entrepreneurial activity in South Africa. Internet access is mostly unavailable or often available only at exorbitant costs and therefore not affordable to populations in rural areas of developing regions. Particularly, in areas lacking affordable and continuous network connectivity a DTN infrastructure could facilitate technology-based micro-entrepreneurship because a DTN infrastructure is simple and low-cost. DTN is an architecture aimed at providing communication in situations where end-to-end connectivity is not available. To ease the development process of DTN applications, the DTN Research Group (DTNRG) [8] has defined an experimental network protocol for challenged networks. The protocol specification is described in detail in RFC5050 [6]. In our use case scenario, the content is distributed to micro-entrepreneurs by means of buses equipped with infostations, named MOSAIC network. Mobile infostations mounted on public buses deliver content to rural areas of South Africa without the support of telecom operators or any other network infrastructures. In this paper, which builds upon previous work [5,12], we discuss the six-month long field deployment and the MOSAIC network in Sect. 2 and describe the experimental setup in Sect. 3. We present initial results and implications in Sect. 4. Related work is outlined in Sect. 5. Finally, Sect. 6 concludes the paper.

Fig. 1. The cinema-in-a-backpack kit (left) to download media content at the bus depot in Siyabuswa, South Africa (right).

2 MOSAIC 2B Network Scenario

MOSAIC 2B is a research project aiming to provide business opportunities for micro-entrepreneurs living in rural South Africa by delivering multimedia content to them in a low cost manner. Since cellular data access is usually unavailable or expensive in rural areas, content delivery will be performed using DTN.

Multimedia content will be delivered by means of DTN-enabled mobile infostations. Infostations are battery-powered Wireless Local Area Network (WLAN)-enabled devices mounted in buses and bus depots We refer to the infostations placed in the bus depots as fixed infostations and the infostations placed in the buses as mobile infostations. Such infostations act as peers that broadcast the content. The multimedia contents are archived at the fixed infostation located at the main bus depot in the city of Pretoria, which is within a 3G/LTE covered area. Every day, such a fixed infostation fetches a list of contents requested by the micro-entrepreneurs from a server located in the Internet cloud, finds such requests in the local archive, and injects them in the DTN network. Micro-entrepreneurs are provided with a tablet which exposes a catalog of movies that are available to be ordered by sending an SMS to the MOSAIC_2B Control Unit (MCU) server in Pretoria. Content is sent from the fixed station in Pretoria, through mobile infostations mounted on buses, to the fixed infostations installed at the rural bus depots, by means of a DTN network. Namely, content is forwarded from one infostation to another as soon as they are in radio range with each other. We have identified three bus depots of the PUTCO bus transportation in Siyabuswa, Vlaklaagte, or Kwaggafontein, about 135 km north-east of Pretoria, which serve several rural communities. Usually, buses take commuters living in rural areas to the city of Pretoria early in the morning and the other way round in the evening. They travel for three hours in the morning and three hours in the evenings in predetermined paths. Thirteen local micro-entrepreneurs living in rural areas near Kwaggafontein, Vlaklaagte and Siyabuswa are equipped with the cinema-in-a-backpack kit that allows them to download content from the final fixed infostation and screen it, e.g. in schools or villages, and in addition to invent and to execute micro-business activities around the screenings, e.g. selling candy, providing health-care related or public information, education, leisure games. Figure 1 (right) shows some micro-entrepreneurs downloading media content at the bus depot in Siyabuswa using their cinema-in-a-backpack kit. They run their own mobile cinema business within the surrounding communities during a period of about five months, during which we monitored their actions and collected valuable data, both from the network performance and the business activity.

3 Experimental Setup

Micro-entrepreneurs were assigned to a "rural" infostation based on their preference. At the beginning of the experiment, micro-entrepreneurs were asked which bus depot they prefer to go to download the content they order. Taking into account the preferred bus depot of each micro-entrepreneur, bus routes and their timetables, we set up each infostation with a static routing table. Buses are assigned to predefined routes and travel between two end-locations every day following a predetermined time-table. In this way, content is forwarded to mobile infostations traveling to the right bus depots. Two buses equipped with mobile infostations are assigned to each route to Kwaggafontein, Vlaklaagte and

Siyabuswa. We have deployed 10 infostations, six mobile (two for each route) and four fixed (one for each bus depot). Once movies are forwarded to the rural infostations, they are stored and a notification email is sent to the micro-entrepreneurs who ordered them. Besides, such an activity is logged to the MCU server via 3G, when available. Note that, we experienced 3G disruptions from time to time while logging infostation activity. Micro-entrepreneurs are allowed to go to the bus depot and download their content whenever they can. However, this approach might lead to memory saturation, resulting in loss of processing power and interruption of the infostation activity. Eventually, micro-entrepreneurs might decide to order a large number of movies and wait for all of them to arrive at the rural infostation, so as to fetch them all at once. Because of the low CPU speed (400 MHz) and the small internal memory space (32 MB RAM) of the computing devices, the amount of stored content in the external memory storage (64 GB USB flash drive) and the number of running processes impacts on the performance of the infostations. Therefore, network resources need to be carefully allocated. Based on the results presented in a previous study [12], and observations regarding contact durations and inter-contact times [4] between mobile and fixed infostations at the bus depots, we set up the mobile infostations with a time-to-live of three days and the external memory storage limit to 30 GB. After that limit, the performance of infostations drastically decreases. The mobile infostations are continuously in contact with the fixed infostations at the rural bus depots approximately from 8pm until 4am, while buses are on the sleeping grounds. They arrive at the main bus depot in Pretoria between 9am and 10am, after taking their passengers to town, and do not leave before 3pm. Once the content is forwarded to the fixed infostations at the rural bus depots, it will be erased after one day to free memory space. However, a back up of all the content is made available in the external memory storage in case the ordered movie is deleted before being delivered to the final recipient. We decided to place a back up of all the content at the fixed infostations in rural areas to avoid unexpected disruptions to compromise the business activity of the micro-entrepreneurs. Such settings are enough to prove the viability of delay tolerant networking to deliver media content to rural under-served regions in a low-cost manner. Thirteen micro-entrepreneurs are provided with a tablet which exposes a catalog of movies that are available to be ordered by simply sending a text message to the MCU server in Pretoria. A new catalog of movies is also delivered to micro-entrepreneurs via the MOSAIC network every two months and notified to them by email. We use encryption and audiowatermarking to ensure a certain level of security and to detect copyright violation. All of the movies are encrypted and audiowatermarks are embedded in the soundtrack. Content is decrypted once the payment is completed and erased from the tablet at the end of the experiment.

4 Performance Analysis

During the 6-month field trial we logged network activities. Because of several circumstances due to MCU glitches, delay with the allocation of buses and

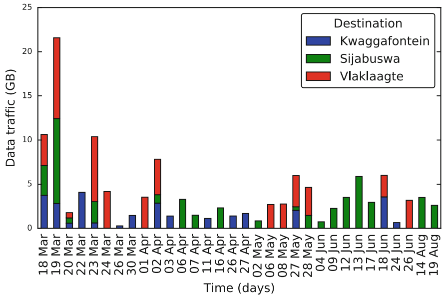

Fig. 2. Data sent by means of the MOSAIC network.

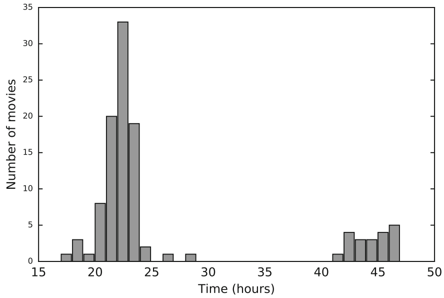

Fig. 3. Distribution of delivery time of movies sent from the fixed infostation in Pretoria to the fixed infostations at the remote bus depots.

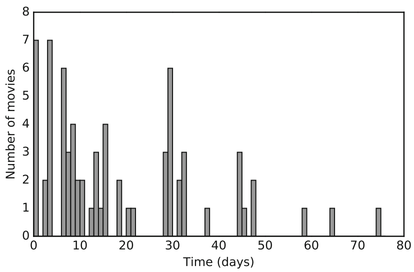

Fig. 4. Time elapsed between the order and the delivery of movies to micro-entrepreneurs.

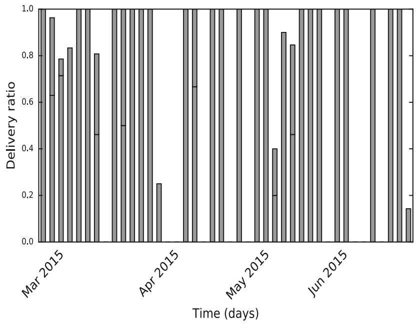

Fig. 5. Daily delivery ratio of the amount of data sent from Pretoria to the rural bus depots (GBs).

bus drivers, time allocated to provide business and marketing trainings, as well as technical support to the micro-entrepreneurs, the experiment lasted about five months. During this time 109 movies were sent through the MOSAIC network. The fixed infostations logged information such as movies injected in the network, movie size, contact times between mobile and fixed infostations, and delivery of movies. Such information allows us to analyse the performance of the MOSAIC network and to estimate the contribution of such an infrastructure to support the mobile cinema business activity in rural areas. To evaluate the MOSAIC network we analyse the delivery ratio and delay of the ordered movies from the bus depot in Pretoria to the rural bus depots. Initially, we investigate whether the current set up can cope with the demand of movies from the micro-entrepreneurs. The plot in Fig. 2 shows the aggregated daily data transmission rate distinguishing between the three rural destinations, from the 18th of March until the 19th of August. Note that, the missing data in July and beginning of August was due to an interruption of the network activity caused by unexpected interruptions of the MCU server. Nonetheless, such disruption did not affected the micro-entrepreneurs' business activity as they could download the movies from the back up stored at each rural infostation. Another disruption, which prevented the fixed infostations from logging network activity via 3G to the MCU, was caused by an unexpected behaviour of the data consumption balancing system of the network operator. For unknown reasons, some of the SIM cards ran out of credit within a few hours after topping up (250 MB data traffic) without performing considerable logging activity. Such behaviour occurred several times, randomly, during the experiment, and affected some of the fixed infostations. The Fig. 2 shows a peak in the data traffic during the first month of the experiment. In particular, on the day with most requests the infostation was able to send approximately 21.6 GBs in total in a single day (March 19th), sending a maximum of 9.6 GBs to the Siyabuswa bus depot. Based on such initial results, and given that the setup can cope with the peak demand, we can argue that the DTN network can handle the daily requests of movies from the micro-entrepreneurs. As soon as content is bundled at the fixed infostation in Pretoria, it is ready to be forwarded to the mobile infostations mounted on buses. The plot in Fig. 3 shows the distribution of the delivery time of movies to the rural infostations. The majority of the movies are delivered within thirty hours, while a second batch is delivered after forty hours. This behaviour is due to buses not traveling during weekends. Figure 3 proves that all movies are delivered within two days and the expiration time-to-live set to three days is sufficient to deliver successfully the content. After all, long or unpredictable delivery time of content would not help micro-entrepreneurs to plan their screening events efficiently. To make sure that the delivery time does not affect negatively the business activity of the micro-entrepreneurs, we consider the time micro-entrepreneurs take before going to download their orders at the rural bus depots. Figure 4 shows the time elapsed between ordering and downloading movies to the tablet at the rural bus depots. The distribution in Fig. 4 shows that the big majority of micro-entrepreneurs go to get the ordered movies after three days, meaning that a two-day delay to deliver content to the rural bus depots is unlikely to cause frustration to them. Such a behaviour shows that the bus network is not a bottleneck for the micro-entrepreneurs' business activity. Note that, the movies downloaded the first day were ordered and injected in the MOSAIC network the first day of the experiment as demonstration to the micro-entrepreneurs. The plot in Fig. 5 presents the daily delivery ratio of the amount of data sent from Pretoria to the rural bus depots. In many cases, data is successfully delivered, with the exception of some days where the delivery ratio is zero. In this case, it is not possible to assert with certainty whether the network failed, for example to deliver movies, or there are logging issues due to 3G disconnections. This might be caused by 3G outages in rural areas. Here, the 3G coverage was often intermittent. In this case, a buffering mechanism for sending log messages should be implemented, that is, if the 3G network is unavailable the logs could be stored locally, and sent to the MCU when 3G connectivity is available. By excluding 3G network outages from the receiver side (when delivery ratio is zero), the DTN network expresses 95% delivery ratio. Nonetheless, if some movies are not delivered through the DTN network, a backup is available at the infostations, thus allowing micro-entrepreneurs to download them.

5 Related Work

Considerable work has been carried out by the scientific community to devise reliable routing strategies in DTNs [1–3]. Initial work focusing on rural environments in developing regions where buses connect a number of villages spread over a large area is conducted by [10]. Their common goal is to provide network access for delay tolerant applications such as e-mail and non-real time web browsing. DakNet [10] was one of the first projects to propose the use of an existing transport infrastructure to bring connectivity to developing regions in India and Cambodia at low cost. The MOSAIC 2B project is in a similar vein as DakNet. However, we make use of delay tolerant networking for transmission of larger amounts of data. Not only this, we use different equipment that we hope brings down the costs further. KioskNet [9] attempted to improve the service provided by rural kiosks in a low cost manner. These kiosks are a means to provide Internet connectivity at a low cost but technical problems led to unreliable service. In KioskNet, buses acted as ferries that carried data to and from kiosks to a gateway that had reliable Internet connection. Our approach is quite similar to KioskNet since we use buses as ferries and a DTN method of communication. However, we differ in the hardware and DTN software used and in the objective of delivering large amounts of media content to the end users.

6 Conclusions

In the MOSAIC 2B project we offer DTN as a technology that is uniquely suited to the challenge of providing network access to people in under-served regions. We present a 6-month long field deployment that provides communities in rural South Africa with cinema experience by equipping a small group of micro-entrepreneurs with the cinema-in-a-backpack kit and training them in the operation of a DTN-enabled micro-franchise. The DTN network performed efficiently in these settings, allowing cost-effective delivery of movies with acceptable delay. Despite some unexpected disruptions, the MOSAIC network performance was satisfactory and delivered 95% of the content within three days. The general flow of ordering, downloading and screening movies worked without any major issues. The quality of the equipment allowed the screenings of movies in these remote areas. In the future, we intend to analyze in more details the DTN-based micro-franchise model and the micro-entrepreneurs's business activity whose operations are enhanced by opportunistic networking.

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