Mobile-Enabled Delay Tolerant Networking in Rural Developing Regions

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***Abstract*—Mobile technology is already playing an important role in the economic and social empowerment of rural communities in developing regions. However, rural areas often suffer from slow and unreliable network infrastructures. This limits access to content and services that may promote economic development. Focusing on under-served areas in rural developing regions, we aim to explore how ICT systems for collective intelligence can be used to foster economic and social empowerment of rural communities. In our model, microentrepreneurs equipped with low-complexity *cinema-in-a-backpack* systems can deliver educational and entertainment content in remote villages. The content is distributed to microentrepreneurs by means of opportunistic (delay-tolerant) networks. In such networks, mobile *infostations* mounted on public transportation vehicles deliver content without the support of telecom operators or any other dedicated network infrastructure. The delay tolerance of opportunistic networks makes them ideally suited to environments with under-developed ICT infrastructures. We discuss the technical challenges behind distributing digital content with a low-cost delivery mechanism and opportunistic networks. We also establish the case for DTN as a socially-grounded approach to mobile empowerment in the context of rural development. Toward this end, we present our work in an ongoing project that provides communities in rural South Africa with cinema experience by training microentrepreneurs in the operation of a DTN-enabled microfranchise.**

I. Introduction

Today, 31% of the developing world's population can access the Internet [1]. However, 90% of unconnected households are in rural areas. Moreover, residential fixed-broadband services are still expensive in developing countries, accounting for just over 30% of average monthly GNI per capita. We aim to reach out to these regions with a low-cost approach for media distribution, towards the goal of enabling universal network access, an important facet of global social and economic empowerment. We are developing and testing a framework that uses Delay-Tolerant Networks (DTNs) to unlock new mobile business opportunities, particularly in rural areas. DTNs offer a viable low-cost alternative to cellular wireless communication networks in areas that are under-served [2]. There is growing interest in opportunistic networks as a special case of DTNs because of their ability to leverage intermittent contacts among mobile radio devices and thereby provide flexible multi-hop connectivity. Opportunistic networking applies the *store-carry-forward* paradigm in which data is stored locally by mobile devices, carried while moving, and forwarded once within transmission range of another device. Such devices communicate only with their direct neighbors using local radio communication like Wireless Local Area Networks (WLANs). DTNs require only minimal, if any, investment in supporting infrastructure, particularly where wireless communication devices are ubiquitous, as in the South African test sites that we will introduce. DTNs do compromise network reliability and quality of service by introducing unpredictable delays as data is physically relayed from one wireless device to another. Applications must be able to tolerate the delays to benefit from DTNs. Relaxing the requirements of fast delivery, data such as emails, photographs, podcasts, and videos can be sent in a delay-tolerant fashion. In this paper, we describe the technology and an accompanying microfranchise model that we are developing to test both the technical and economic viability of DTN.

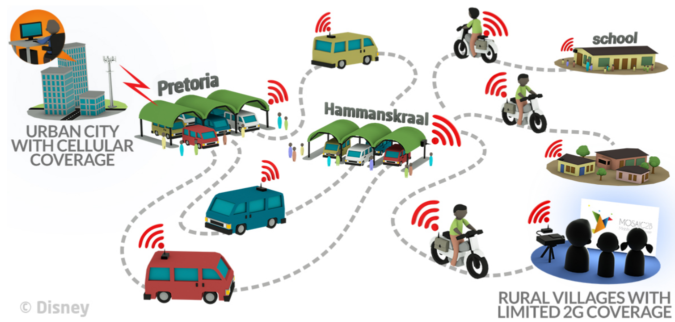


Fig. 1: A delay-tolerant network between the city of Pretoria and remote villages.

In the following, we introduce the target social and economic context in Section II, the mobile communication penetration in rural South Africa in Section III and propose the testing of the DTN technology for the economic opportunity behind the DTN technology in the developing world in Section IV. In Section V we present the cinema-in-a-backpack device and DTN network components. We present the use case scenario in Section VI, our initial experimental study in Section VII and some related work in Section VIII. Finally, Section IX concludes this paper.

II. DTN in Social and Economic Context

We propose that DTN is a technology that is well suited to providing network access to people in rural developing regions. To understand this claim, it is necessary to first understand the social and economic context. In many parts of sub-Saharan Africa, including our test site, the availability

Fig. 2: Taxi stations in Pretoria and Hammanskraal, South Africa.

of network and communication infrastructure is outpacing household access to water and electricity. Mobile phone adoption has been in the double digits for years, making it the mostly quickly adopted, and possibly the most transformative technology for economic development in history [3], [4]. Therefore, mobile devices are a promising medium for DTN network transmission in the rural developing world. DTN has been popularized as a network solution in the event of a disaster scenario, but among the rural poor there are reasons to believe that it may coexist meaningfully with other modes of network transmission. For one illustrative comparison from South Africa, [5] reports that consumers pay on average five times more than Americans on mobile service, as a percentage of monthly income. Because it can be deployed on mobile phones that are already widely available in the developing world, DTN may provide a very low-cost complement to traditional infrastructure-heavy forms of network distribution.

III. Mobile Communication in Rural South Africa

This study focuses on South Africa for a variety of reasons, but chief among them is that South Africa's present-day mobile penetration best reflects that of the future of the rest of the developing world. Ubiquitous mobile penetration may be one prerequisite for effective DTN service. While less than 5% of South Africa's rural poor have tap water or electricity, more than 17% (paradoxically) have access to television, and 70% to radio [6]. And however popular these traditional content distribution channels may be among South African rural populations, mobile devices have penetration even more deeply. Per capita, ownership of mobile devices is over 100% [7], though only 50-60% of people have active service at a given moment [8]. Additionally, South Africa has the highest smart phone and tablet penetration in sub-Saharan Africa [9], [10] and it is one of the few African nations with 4G infrastructure [11]. Relative to other developing countries in Africa and abroad, the South African government is in the unique position to be setting ambitious targets for universal internet access, with one recently approved government plan to provide 90% of citizens with bandwidths of at least 5 Mb/s by 2020 [12] Compared to the developed world, internet use is unique in sub-Saharan Africa in that mobile phones dominate other kinds of access to the internet. In the case of Nigeria, 60% of internet users access the network through their phones [13], patterns of internet use extend to rural areas as well, with 29 percent of rural South Africans being able to access the internet by mobile phones. About 60% of mobile phones are basic phones (2G with SMS), with about 20% each split between feature phones (2.5G) and smartphones (3G) [7], [10]. Despite this seemingly low bandwidth view into the internet, internet usage patterns in sub-Saharan Africa are very similar to those in the developed world, with social networking, instant messaging, email, and music coming in as the top four uses [9], and half of the population accessing sites like Facebook by phone [14]. And all signs point to the continued spread of mobile access throughout Africa [15].

IV. Testing DTN for Economic Opportunity and Robust Network Access

Sub-Saharan Africa -and South Africa in particular- may offer a natural environment for evaluating DTN as a tool for economic empowerment in rural developing areas. Many features point to DTN as a promising form of network distribution: they have relatively sparse and poor populations, very high mobile penetration, high demand for internet access, a heavily mobile-centric view of the Internet, and access to only unstable or underdeveleped traditional network infrastructure. DTN is a new and untested technology in the developed world, and it is even less proven in the uncertain environments of the developing world. It is costly and difficult to test new technologies like DTN in the field, particularly early in their development, and in the unfamiliar, under-resourced, and under-researched environment of rural Africa. From a technological perspective, such environments present challenges and opportunities that cannot be predicted in advance. Field testing allows user insights to inform early design decisions and exposes researchers quickly to unexpected real-world factors that may influence their work. But it is not sufficient to establish the technological viability of DTN, especially without consideration for the social and economic realities of these areas. How might tests of new technologies, entirely divorced from local need or knowledge, impact people who live around a network test site? We propose that it is as important to establish the economic potential of DTN to improve the lives of rural populations as it is to establish its technological viability. We therefore introduce the cinema-in-a-backpack as a use case for DTN and as a facilitator of subsistence microfranchise opportunities in rural South Africa.

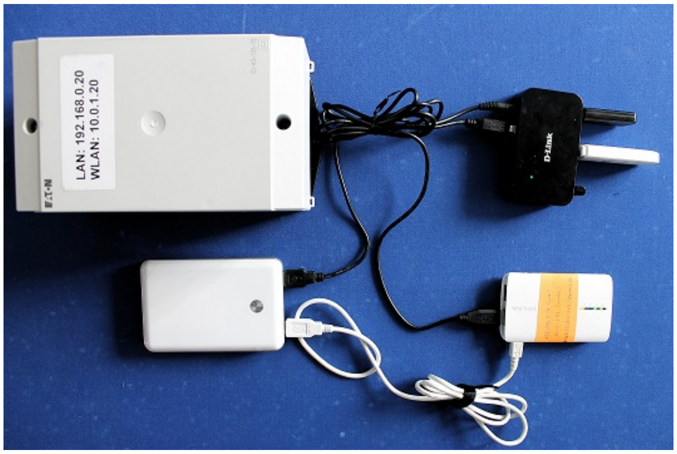


Fig. 3: TP-Link TL-MR3040 router, portable battery, USB hub, GPS receiver, 3G dongle, and external data storage.

Fig. 4: Pico-projector and speakers for the cinema-in-a-backpack.

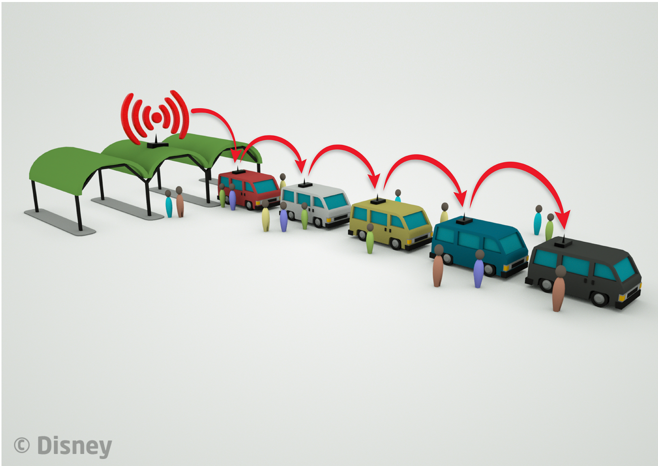
Entrepreneurs in a microfranchise are agents with local knowledge and the motivation to test technologies that may improve their economic circumstances. Franchises are pre-defined businesses that provide entrepreneurs with access to licenses, specialized capital, and a variety of brand and operational guidelines. They define an interface between entrepreneurs and property owners. Within the scope of franchises, *microfranchises* distinguish themselves with low capital requirements, and more loosely-specified business plans, making them suitable for deployment in regions with large informal sectors. The microentrepreneurs that operate microfranchises are left with more freedom to adapt their small business to local conditions. Since microfranchises provide a flexible interface with local conditions, researchers can use them as testbeds for experimental technologies. Microfranchises are loosely specified, leaving room for entrepreneurs to use local knowledge, take advantage of unexpected opportunities, and adapt to unexpected constraints. But they are also designed before being offered to entrepreneurs, and can consequently be crafted to encode domain expertise and experts' insights into how a business might best leverage the strengths and manage the weaknesses of an experimental technology. We will test the cinema-in-a-backpack microfranchise as a testbed for the socio-economic benefits and technological viability of delay-tolerant networking in rural South Africa.

V. A DTN-ENABLED CINEMA-IN-A-BACKPACK

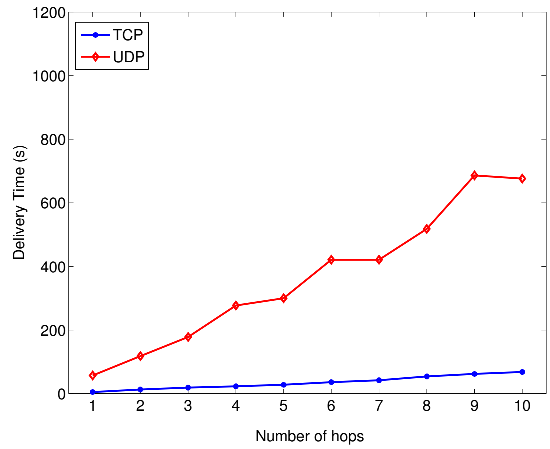
Microentrepreneurs will be provided with cinema-in-a-backpack systems that will enable them to deliver educational and entertainment content in remote villages. The cinema-in-a-backpack is a relatively cheap and portable package on which microentrepreneurs may base a business projecting movies and selling tickets or concessions. The backpack consists of a tablet, a mobile infostation, a projector, speakers, and battery. Mobile infostations carried by microentrepreneurs allow them to be part of the DTN network. Infostations will transmit media content through the network as entrepreneurs request it for cinema showings. Microentrepreneurs can access multimedia content through their tablets, which have been modified to ease interaction with the delay tolerant network. They can connect to the DTN by USB cable or ad-hoc WiFi connection and their projectors can connect to the tablet via HDMI or VGA adapter. The projector must have sufficiently high audio and visual quality for the delivery of a satisfying cinema experience. Furthermore, it must be robust enough to endure the ruggedness of rural environments. The chosen pico-projector and speakers is shown in Figure 4. Since microentrepreneurs may not have access to a reliable and predictable power supply, they must also be provided with a rechargeable external battery.

Infostations are wireless routers equipped with external memory storage, battery supply, USB hub, GPS receiver, and 3G dongle (see Figure 3). We have selected the TP-Link TL-MR3040 Ver. 2.0 WiFi router for the infostations. Each router will be connected to the 3G dongle, GPS receiver, and memory storage through the USB hub. All of the infostations have sufficient memory to store all the data sent by the source in an epidemic fashion. When available, the cellular network and GPS receiver will assist in monitoring the DTN network. The 3G dongle will allow each infostation to send information for evaluating network performance and mobility traces (GPS coordinates) in real time. With this infrastructure we will be able to monitor the system and quickly detect failures or unexpected behaviour. All of the infostations, except those carried by the microentrepreneurs, will be connected to car batteries or local electric infrastructure. Microentrepreneurs will be provided with rechargeable external batteries to power the infostations that provide them access to the DTN.

The infostations have been installed with an OpenWrt release [16], an embedded operating system based on the Linux kernel, and the IBR-DTN, a C++ implementation of the Bundle Protocol (rfc5050) designed for embedded systems [17], [18]. IBR-DTN provides different routing schemes and supports the TCP and UDP convergence layers.

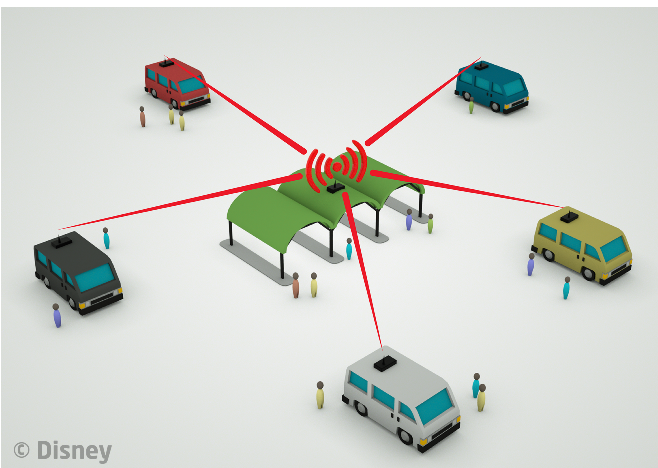


(a) Taxis queueing at the taxi rank and connected in line from the fixed infostation.

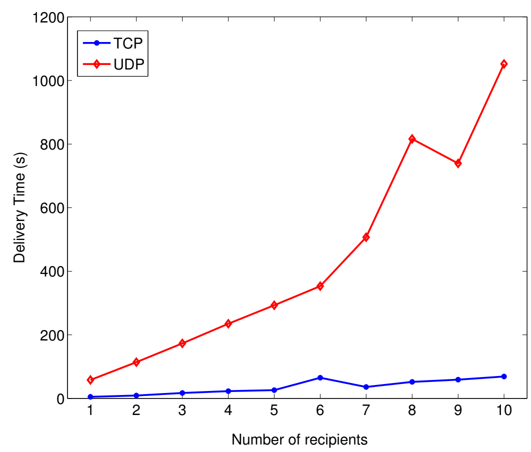


(b) Delivering 10 MB file to all of the nodes in a line network through n hops.

Fig. 5: Line network topology.



(a) Taxis scattered nearby the taxi station and directly connected to the fixed infostation.

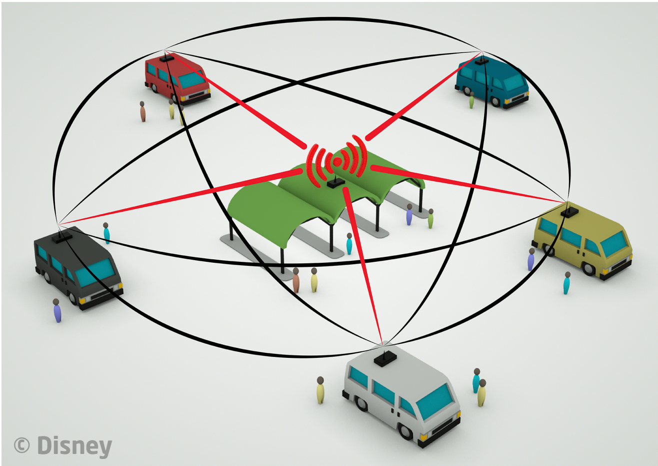


(b) Delivering 10 MB file to all of the nodes in a star network, from 1 to 10 recipients.

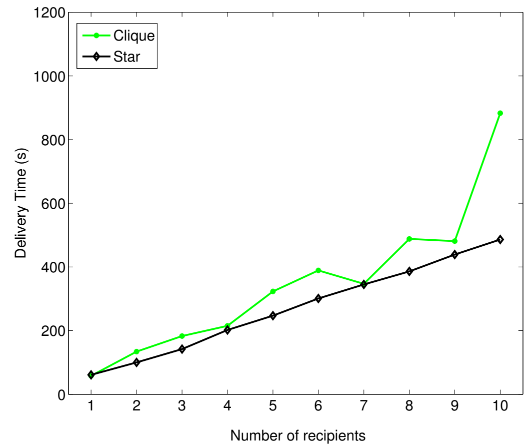
Fig. 6: Star network topology.

VI. Use Case Scenario

We are developing DTN as a platform for building economic opportunity in developing areas. Instead of relying on cellular data, we use a DTN approach to provide affordable low-infrastructure channels for the distribution of multimedia content by microentrepreneurs. We will equip microentrepreneurs with the required tools and train them in the necessary skills to launch mobile cinema businesses in their own communities. Multimedia content will be delivered with the help of an opportunistic network implemented via mobile infostations mounted on public transport vehicles in regular contact with urban areas (and the higher quality communication infrastructures associated with them). Infostations will be battery-powered WLAN-enabled devices. Entrepreneurs will also be equipped with infostations to provide them access to the DTN. In this way, they will receive media content while sharing their own network resources. Each infostation will act as a peer in helping to distribute cinema content to our community of entrepreneurs. Our study will be based in the community of Hammanskraal, a small town 42 km north of Pretoria, South Africa. In areas like Hammanskraal, 3G coverage is often unavailable, and even when it is not, it is too expensive for local populations. In the scenario we are designing, entrepreneurs will be granted access to the DTN network and they will be able to request content from it. The request will be sent through the DTN and ultimately downloaded via the Internet to a fixed infostation in Pretoria (see Figure 1) That infostation will function as the gateway between the internet and the DTN. The infostation will be located in proximity to public transportation vehicles with regular service to Hammanskraal.



(a) Taxis scattered nearby the taxi station and fully connected with each other and with the fixed infostation.



(b) Delivering 100 MB file to all of the nodes in a fully connected network, from 1 to 10 recipients.

Fig. 7: Clique network topology.

From the gateway in Pretoria, data will be sent via an epidemic protocol throughout the entire DTN network. Data is sent in bundles, the protocol data unit of DTN, to mobile infostations mounted on public transportation vehicles as they come within radio range. The mobile infostations will serve as intermediate relays, which will carry the content between the gateway and the infostations carried by the entrepreneurs in Hammanskraal. Figure 1 illustrates the DTN scenario in which vehicles travel between two stations. Located far from Pretoria, microentrepreneurs will receive multimedia content via public transport vehicles that, on their regular routes, will transmit content to fixed infostations installed in stations or other stops in Hammanskraal. There are approximately 150 taxis and other types of mass transit travelling between Pretoria and Hammanskraal every day, any of which have the potential to ferry data between infostations. Mass transit around Pretoria is driven by a large informal economy of private shuttles. The system does not follow a fixed timetable. It serves Hammanskraal in the morning (from about 6:00am to 9:00am) and in the evening (from about 4:00pm to 7:00pm). During these peak times, they work mostly as shuttles; stopping at stations or taxi ranks until they are fully loaded with passengers. During the rest of the day they are in Pretoria where they provide regular taxi service around the city. Using this physical distribution system, microentrepreneurs will be able to download content from the fixed infostation in Hammanskraal or whenever they are in contact with other DTN nodes. Once microentrepreneurs are in proximity with an infostation, they can download their content via WLAN with their mobile devices.

VII. Experimental Study of Media Distribution

In this section, we investigate the capability of the infostations to deliver media content. By leveraging our knowledge of the DTN network topology, we can provide microentrepreneurs with reliable network access on which they can base a cinema business. We evaluate the performance of two traditional network protocols, TCP (Transmission Control Protocol) [19] and UDP (User Datagram Protocol) [20]. While TCP provides reliable, ordered and error-checked delivery, UDP does not guarantee delivery or ordering of the data traffic. We reproduce three possible network scenarios that can occur during the field trial in South Africa. As previously mentioned in Section VI, one fixed infostation will be placed at the taxi rank, which will send data to several mobile infostations ferried by taxis. In all of our studies here, the source node is the fixed infostation. All of the nodes are at a distance of 1 metre from each other and in line-of-sight. We start by considering the simple line topology, in which infostations are connected to each other in a queue and data is forwarded hop-by-hop to all of them (as shown in Figure 5a). Figure 5b shows the time needed to deliver the content to an increasing number of receivers. It takes 68 and 676 seconds respectively to deliver 10 MB to ten infostations using TCP and UDP. As shown, the UDP distribution expresses longer delivery time with respect to TCP. We see the same results with a star network topology. In the start network scenario, the sender multicasts the same content to one or more recipients independently(Figure 6a). Evaluating the case of one sender and an increasing number of receivers, we find no difference between the TCP distributions in Figure 5b and in Figure 6b. Delivering 10 MB data to ten infostations, TCP takes 69 seconds while UDP takes 1052 seconds, as before. We observe that TCP consistently outperforms UDP. This is mainly because the UDP datagram convergence-layer has a shorter sliding window compared to TCP. Consequently, the transmission delay has a much greater impact on the effective bandwidth utilization. Given these initial results, our final analysis compares the performance of TCP in two different network topologies, the star and the clique. In the clique network scenario, all of the infostations, mobile and fixed, are connected with each other (see Figure

7a). In this case, we set up the source node to send 100 MB, a large enough load to stress the network. Data is sent epidemically through the DTN network. Epidemic [21] is a well known routing protocol, often used as benchmark by the delay tolerant network research community. It does not use any knowledge of the system to forward data and provides a theoretical upper bound in terms of delivery ratio when the buffer size is infinite. Such a routing protocol might be employed in the South Africa scenario (described in Section VI). It is interesting to observe that TCP shows small improvement in the star network with respect to the clique network in almost all cases (Figure 7b), despite its lower density of connections. Although the clique network has higher connectivity, it does not help in improving the delivery time.

This could be due to the large amount of information exchanged between the nodes before forwarding data. Each node communicates its own content to all of the other nodes in radio range. Generating and forwarding such additional information increases network overhead which could be a potential source of delay. Such a behaviour has stronger impact in a clique network, in which each node establishes a connection with all of the others. Higher connectivity implies higher network overhead which might congest the network at DTN layer.

VIII. Related Work

Wireless networks exploiting public transport systems have been attracting attention in recent years. Initial work focused on rural environments in developing regions where buses connect many villages over a large area [22]–[24]. Their common goal is to provide network access for delay tolerant applications such as e-mail and non-realtime web browsing. DakNet [22] uses computers with Wi-Fi radio attached to buses routed between villages. E-mail and other data are downloaded to the village and uploaded for transport to the Internet or to other villages along the bus route. On the same bus network, a system of throwboxes [25], [26] was deployed to enhance the capacity of the DTN. KioskNe [27] is a network of rural Internet kiosks that provide data services in remote regions. Vehicles with on-board computers ferry the data between the kiosks and gateways connected to the Internet. In these cases the set of neighbors for every node is usually small and does not change frequently over time; usually encounters are highly predictable. TACO-DTN [28] is a content-based dissemination system composed of fixed and mobile infostations that allow mobile users to subscribe to media contents for a period of time. Campus bus networks designed to serve college commuters are proposed in [29]–[31]. In these settings opportunistic networks are usually characterized by a relatively small number of nodes when compared to a fully fledged urban environment.

IX. Conclusion

Rural areas of developing regions often suffer from slow network infrastructures, if they have any at all. This limits access of local populations to content and services that may provide economic opportunity. We offer DTN as a technology that is uniquely suited to the challenge of providing network access to people in such environments. We describe our DTN framework and introduce the microfranchise model to test both the technological and economic viability of this new technology. We present our work in an ongoing project that provides communities in rural South Africa with cinema experience by training microentrepreneurs in the operation of a DTN-enabled microfranchise. We introduce the target use case scenario and discuss the technical challenges behind distributing digital content with a low-cost delivery mechanism and opportunistic networks. networks. In parallel with the development of the technology we examine the social and economic context of our intervention. Our aim is to train a group of small cinema microentrepreneurs whose operations are enhanced by opportunistic Given the ubiquity of mobile phones in the area of our study site, we believe that DTN may improve network access and the distribution of educational and entertainment content in rural environments, despite the relative underdevelopment of more traditional kinds of infrastructure like roads and electricity. In this initial work, we evaluate the capability of our experimental wireless devices to deliver media content through different network topologies and two network protocols. We will develop and test a framework that uses DTNs to unlock new mobile economic opportunities in under-served rural areas.

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