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DIY Model for Mobile Network Deployment: A Step Towards 5G for All

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ABSTRACT

Mobile phones and innovative data oriented mobile services have the potential to bridge the digital divide in Internet access and have transformative developmental impact. However as things stand currently, economics come in the way for traditional mobile operators to reach out and provide high-end services to under-served regions. We propose a do-it-yourself (DIY) model for deploying mobile networks in such regions that is in the spirit of earlier community cellular networks but aimed at provisioning high-end (4G and beyond) mobile services. Our proposed model captures and incorporates some of the key trends underlying 5G mobile networks and look to expand their scope beyond urban areas to reach all by empowering small-scale local operators and communities to build and operate modern mobile networks themselves. We showcase a particular instance of the proposed deployment model through a trial deployment in rural UK to demonstrate its practical feasibility.

CCS CONCEPTS

• **Networks → Mobile networks**;

KEYWORDS

5G mobile networks; universal Internet access; rural and developing regions; network architecture and deployment models

1 INTRODUCTION

Mobile phones undoubtedly are an integral part of people's lives in much of the world helping them stay socially connected, have access to information etc. wherever they may be. Their use in the developing world has been rising rapidly and has been innovative too, going beyond these usual benefits to enable better governance, improved citizen engagement in democratic processes, better health monitoring, creating economic opportunities, and so on. In view of their role as Internet end-hosts in modern mobile networks, they can be seen from the perspective of broadband Internet access and associated impact on the economy. According to World Bank estimates, every 10% increase in broadband Internet access translates to 1-2% rise in gross domestic product (GDP). Moreover, next-generation 5G mobile networks, which will start being rolled out in a few years, are expected to have even greater impact on the global GDP, sustained over a longer term period [13].

Yet, we are still quite some distance away from universal data oriented mobile access. Mobile services reach 95% of the world's population today but this is limited to only GSM/2G access (mobile voice and SMS) and even so mobile subscriber penetration is relatively lower at 66% [10]. From an Internet access viewpoint (including via mobile networks), more than half the world's population lacks access, with per capita Internet users in very low income countries even lower than 15%. The major challenge lies in taking the Internet connectivity via traditional means beyond the major urban centers to rural and remote areas [5].

Traditional mobile operators have little economic incentive to expand the reach of their infrastructure to provide high-end 4G and beyond data oriented services for scattered and sparsely populated areas as well as for low-income regions with small number of prospective subscribers. Universal service obligations included as part of mobile spectrum auctions in developed countries also have not achieved the intended service coverage goals in practice. The traditional approach to mobile service provisioning also lacks the flexibility to cater to the particular requirements of developing region settings such as local services and content delivery. In recent years, a cost-effective alternative approach has emerged in the form of community cellular networks [3, 11, 12, 23, 25, 28], leveraging open source platforms like OpenBTS, minimizing power consumption by adapting to demand and enabling local services. However these efforts only offer voice and SMS type services as with GSM.

In this paper, we propose a do-it-yourself (DIY) model for deploying mobile networks in under-served regions that is in the spirit of above mentioned community cellular networks but aimed at provisioning high-end (4G and beyond) mobile services. Our proposed model is in tune with the increasing openness (in terms of ecosystem with IT/cloud vendors and verticals, platforms, spectrum types, services, etc.) and cloudification of mobile networks in the run up to 5G. It is meant to enable and ease deployments at low cost by a new set of non-traditional operators (e.g., communities, local small-scale mobile network operators) in areas with market failure and limited availability of mobile services, thereby allowing these areas to leapfrog towards 5G through bottom-up initiatives.

Specifically, the network architecture based on our model consists of three main components. Firstly, the core network component is realized as a commodity and customizable cloud service. Secondly, the access network component is realized via plug-and-play small cell base stations, ideally leveraging open software platforms (e.g., OpenAirInterface [21], srsLTE [1], OpenCellular [9]), software radios and unlicensed/shared spectrum, and commodity end-user devices (smartphones and MiFi devices). Thirdly, the access and

[1] https://github.com/srsLTE/srsLTE

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core networks are interconnected via a low cost backhaul infrastructure. Depending on the deployment setting this could be realized differently using a different combination of wired/wireless technologies (e.g., fiber, satellite, microwave, long-distance Wi-Fi). We in particular highlight the potential of exploiting TV white space (TVWS) spectrum (given the ample availability of this spectrum and its propagation characteristics) to enable a low-cost backhaul with fewer number of intermediate backhaul relays, especially with aggregation of multiple TVWS channels [16]. To demonstrate the practicality of the above outlined model, we present a trial deployment of a particular instance of this model in a rural area in the UK with poor conventional market-driven broadband/mobile infrastructure. We should note that our proposed deployment model is complementary to various recent proposals that can be viewed under the umbrella of 5G for universal access, including the use of drones or unmanned aerial vehicles (UAVs) [6, 26]; white space spectrum [17, 22]; millimeter wave (mmWave) spectrum [7, 18, 19]; and Massive MIMO [8].

2 CHALLENGES FOR DEPLOYING MODERN MOBILE NETWORKS IN UNDER-SERVED REGIONS

Deploying mobile networks is challenging in rural/developing regions. There are a range of factors that constrain such deployments including the low population density and sparse distribution; affordability; the location of nearest Internet point-of-presence (PoP); the unreliability and limits of the power sources; and the deployment area terrain. These factors have major influence on the deployment cost, architecture (both access and backhaul networks) and reliability. Here we elaborate on some of the key underlying challenges, which especially hinder deployment of data oriented current and emerging mobile networks in such regions.

High Infrastructure and Operational Costs. Deploying mobile infrastructure in rural and developing regions is seen to be economically unattractive for traditional operators to recoup the high (access and backhaul) infrastructure cost and recurring operational expenses from the small number of subscribers that would be served. For non-traditional operators, deployment using licensed spectrum may be prohibitively expensive. Cost of powering base stations is also an issue in developing regions as noted in prior work [11].

Lack of Affordable Backhaul (Middle-Mile) Network Infrastructure. This is a crucial part of the end-to-end connectivity to bridge local access networks with the wider Internet, and also dictates their effective capacity and reliability. Both wired and wireless backhaul solutions have been considered in the rural Internet access context. Wired backhaul solutions such as fiber offer high capacity and reliability but with a high cost that is proportional to the required distance and capacity. Wireless solutions, on the other hand, can be relatively cost-efficient but challenging to match the capacity and reliability of wired approaches as they need to grapple with issues like type and amount of spectrum available; terrain and climatic conditions; power availability; deployment and maintenance costs.

Limited Flexibility. Proprietary black box solutions employed in conventional mobile network deployments limit the flexibility needed for rural and developing region settings. The market demand is different from one community to another, therefore, a fixed and rigid deployment model may be insufficient to address and handle the diversity of service requirements.

3 DIY XG MOBILE NETWORK DEPLOYMENT MODEL

To better address the aforementioned challenges and accelerate the arrival of high-end and flexible mobile services to under-served regions, we propose an alternative DIY deployment model for such regions. Before elaborating our proposed model, we first outline the design principles that shaped it.

3.1 Design Principles

Low Cost. As already stated, high cost can seriously limit the mobile service usage in under-served regions but also their availability in the first place. Therefore being cost-effective is paramount. This could be achieved via the use of unlicensed/shared spectrum, open source software platforms, software radios and virtualized network functions over commodity hardware and cloud infrastructure.

Ease of Deployment and Operation. Plug-and-play deployment is essential to lower the initial deployment costs and then to organically grow the infrastructure with new users. Equally, automated and flexible network management is key to lower the operational costs, especially in settings with limited technical know-how, and to add/adapt services as per the evolving needs of the target community.

Flexibility. In under-served regions, different communities present different demands and their affordability of mobile services can also be significantly different. For example, agricultural communities would need the cellular data service to boost their farm productivity using different Internet of Things (IoT) applications [27]. The service requirements for such IoT applications can vary from few hundreds of Kbps for basic monitoring applications to multiple Mbps for precision farming or agricultural drones types of application. Another example is the remote healthcare applications that help to increase the quality of care in the remote communities. These eHealth applications have different service requirements (e.g., higher data rates, low latency). This diversity in service requirements leads to differing technical requirements between different deployments in terms of backhaul link capacity, core network processing capability, etc. Thus, flexibility in being able to accommodate such requirements in an affordable manner is desirable.

Interworking with other mobile networks. Most community-driven local mobile networks do not interwork with other mobile networks (commercial or otherwise). This prevents the user of a local mobile network from using the same SIM card when outside the coverage area of that network. It would however be desirable to have users transparently access mobile services no matter where they are and to communicate with mobile users from other networks. There is some recent work addressing such interworking issues, e.g., leveraging VoIP gateways or service providers to allow the mobile users in a local community to connect with external users [2, 14]; and extending the footprint of commercial networks with local cellular networks [24].

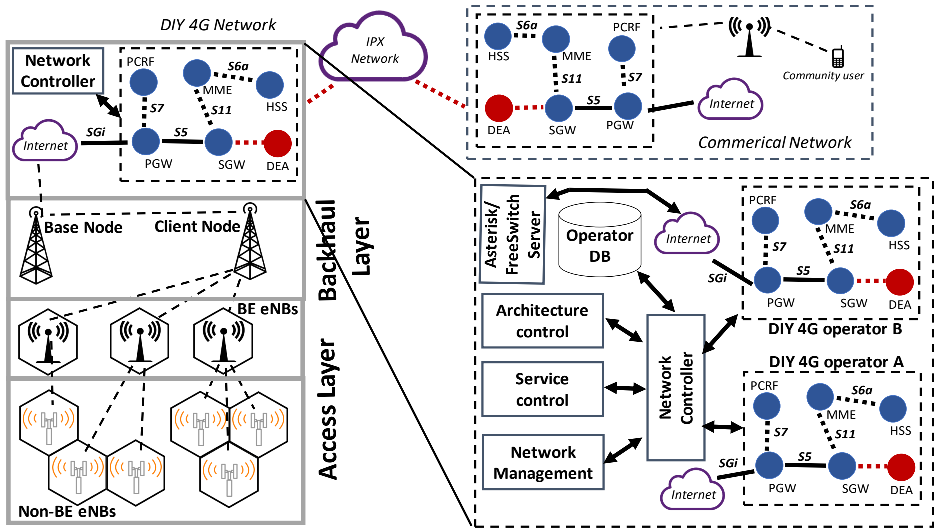


Figure 1: Schematic illustration of of DIY xG mobile network architecture considering the case of 4G/LTE.

3.2 Architecture

The proposed deployment model (illustrated in Fig. 1) is guided by the above principles. It consists of three main components/layers: access, backhaul and core network layers.

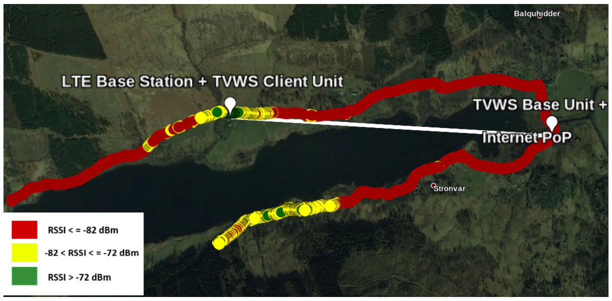
Access Network Layer. Access network infrastructure in our model can comprise of two types of base stations (eNodeBs/eNBs in 4G/LTE) depending on whether they have direct backhaul connection to the core network. End users in this model either connect via MiFi devices when inside their homes or directly from their smartphones otherwise. Backhaul enabled base stations, in addition to interfacing with the backhaul and serving associated end users, also serve as traffic relay for non-backhaul enabled base stations. Capability of base stations can be realized either with commercial (LTE) small cell base stations or via open source software platforms like OpenCellular, OpenAirInterface or srsLTE along with software radios. Spectrum wise, several different possibilities exist including TVWS spectrum as in [4] and unlicensed/shared spectrum via MulteFire[2] like technology.

Backhaul Network Layer. With cost optimization in mind, we consider wireless backhaul as the suitable option for this layer. Among the various wireless alternatives, we believe TVWS spectrum is particularly attractive as a low cost means for backhaul connectivity in view of its superior range and non-line-of-sight propagation characteristics and given the ample availability of this spectrum in rural and developing regions [16]. Both these in turn translate to lesser amount of backhaul infrastructure (fewer relays) for connectivity over a given distance with TVWS spectrum (and corresponding reduction in deployment costs) as well as the potential for high bandwidth connections like the other expensive alternatives (e.g., fiber) through aggregation of multiple TVWS channels. While in general the backhaul layer can comprise of multiple relays in Point-to-Point (PtP) or Point-to-Multi-Point (PtMP) configurations, the simplest scenario involves a single PtP link with access network end serving as a client to the other Base node (as shown in Fig. 1).

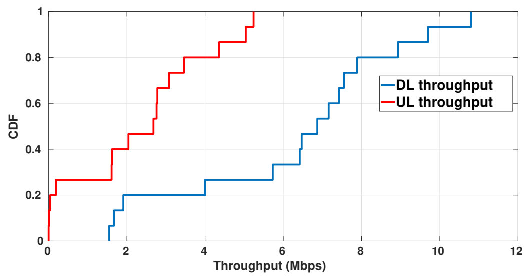
Core Network Layer. For reasons of cost, flexibility and ease of management, the core network layer in our model is realized as a virtualized service over a commodity cloud infrastructure. Broadly speaking, this layer is made up of two types of virtual network functions: (i) *Core network functions* that implement the key functions of a mobile core network (e.g., MME, HSS, SGW etc. in 4G/LTE networks); (ii) *Orchestration functions* which generally deal with centralized network management and control including architecture control, service control and network management. The architecture control is responsible for maintaining and controlling the current network architecture and RAN configurations of all the underlying DIY xG networks. This helps the network controller to efficiently manage the underlying access and backhaul networks and adapt their configuration parameters (e.g., operating frequencies). Service control implements the set of functions that are responsible for customizing/expanding the set of services offered within a community, which in turn can impact different network layers (e.g., increasing backhaul capacity, access network bandwidth, the core processing requirements). Network management focuses mainly on monitoring the underlying backhaul and access networks and generates periodic reports to the network controller. The operator database is a key component that maintains all the information about the underlying networks and their statistics such as the number of subscribers and the running services. Note that due to realization of this layer via virtual network functions in the cloud, multiple instances of core network functions corresponding to different deployments can be concurrently supported on different virtual machines (VMs) while at the same time allowing them to customizable with different set of policies and services. The network controller is responsible for applying the orchestration control functions on the respective core network instances.

Roaming capability when the user from the DIY xG network is outside its coverage but within that of another mobile network (e.g., a commercial mobile operator's coverage area) can be supported via

[2] https://www.multefire.org/



(a)



(b)

Figure 2: (a) Measurement based base station coverage map of the deployment area; (b) CDF of uplink/downlink throughputs measured at 15 different locations across the coverage measurement survey path.

a combination of roaming agreement/partnership setup between the cloud based core of the DIY network and other networks, and standard home routing; the latter requires a signaling connection between the visited core network and the home core network to be established to allow the user to authenticate and register under the visited network. Through the S6a interface and using Diameter protocol and diameter edge agent (DEA), this signaling is carried over an IP exchange (IPX) network between the visited network and home network.

4 TRIAL DEPLOYMENT

To demonstrate the feasibility of the proposed deployment model in practice, we did a trial deployment of a particular instance of this model in Balquhidder area in rural Scotland with a cohesive and vibrant community of 200 households and supporting more than 95 diverse businesses. Due to the poor broadband and mobile infrastructure in this area, an initiative driven by the community is in process to bring fiber connectivity to majority of the properties but about 15% of them would be too expensive to reach through community fiber roll out initiative so we target those households through this trial deployment in a partnership involving the University of Edinburgh, the Balquhidder community, Microsoft Research (Cambridge) and WhitespaceUK[3].

The deployment consists of a single LTE base station connected to the core network in the cloud via a TVWS backhaul link to the Internet POP with fiber connectivity, as shown in Fig. 2a. For the access layer, we use IP Access [15] E40 small cell LTE base station and Novatel 6620 MiFi devices as end-user devices. The access layer is configured to use a 5MHz channel in LTE band 13 in the 700MHz supported by a non-operation development licence from Ofcom and after consulting an Ofcom-endorsed TV white space database. For the 1.6Km PtP backhaul link across the lake (Loch Voil) with considerable foliage, we use Adaptrum [1] TVWS hardware equipped with 11dBi Yagi antennas on 2m poles on each end and operating on one 8 MHz TVWS channel around 500MHz, supporting a link data rate of 12Mbps. For the core network, we leverage the ECHO core network service instantiated on Azure cloud [20]; each of the core network layer components in the cloud is a Standard-DS3 VM with 4 cores.

To assess the coverage and throughput performance with this deployment, we conducted a systematic measurement campaign in the area around the base station with an Android smartphone connected via a MiFi device to the base station. Fig. 2a shows the coverage map from the RSSI measurements. The green and yellow colored points represent good to moderate coverage (with an average RSSI level of -75dBm) due to them falling in the main beam of the 120 degree sector antenna used at the base station, including several locations on the other side of the lake from the base station. Points outside of the main beam shown in red color exhibit poor coverage with an average RSSI level of -88dBm. This indicates the role of choosing the appropriate antenna and its orientation depending on the deployment setting to ensure good coverage.

In addition to coverage, we also measured uplink/downlink throughputs seen at 15 different locations from among those where RSSI levels are sampled for the coverage map. Distribution of these throughputs is shown in the form of CDFs in Fig. 2b. While the maximum downlink throughput is almost the same as the backhaul link rate, median uplink and downlink throughputs are around 3 and 7Mbps, respectively. For those locations falling in the main beam of the base station antenna, the average throughput values are higher (8.5Mbps in the downlink and 4.4Mbps in the uplink). Even when a location is outside of the main beam but has sufficient coverage to be associated with the base station, the average throughputs are reasonable at 3.7Mbps (downlink) and 0.74Mbps (uplink). Overall these results show that mobile data services from commodity smartphones can be supported with the proposed model. With modern small cells capable of handling up to 64 devices, by scaling the channel bandwidth of the access base station and backhaul link capacity, per user and system throughputs can be correspondingly scaled up to support even more bandwidth hungry services.

We close with a brief discussion on the deployment and operational costs with our proposed model. Generally speaking, these costs are highly dependent on the deployment setting, number of users and their service requirements. Although we used commercial small cell and TVWS hardware not optimized for this use case, we expect the deployment cost (CAPEX) can be brought down to within few thousand dollars at most, especially with open source platforms. OPEX on the other hand is dependent largely on cost of cloud based core service and optionally the cost of accessing the TVWS database. As core related cost is linked with the amount of traffic handled by the cloud, it can be significantly reduced by limiting only the signaling traffic to go to the cloud and rest via a local breakout. With such optimizations, we expect the recurring costs can be reduced to well below 1 USD per subscriber per month.

[3] https://www.whitespaceuk.com/

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