The Village Base Station

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1. INTRODUCTION

Cellular communications, including handsets and base stations, have become ubiquitous technologies throughout the developing and developed world. Roughly three billion users spend large portions of their income on these basic communications [1]. However, the remaining half of the world currently has limited access, in large part due to lack of network coverage. Some areas do not have a high enough population density to support a traditional cellular deployment. Other areas are too far from established infrastructure to make a deployment economically feasible. This leads to many rural areas where there is no network coverage at all.

To resolve this issue, in this position paper, we propose the *Village Base Station* (VBTS), which provides four main benefits:

- flexible *off the grid* deployment due to low power requirements that enable local generation via solar or wind;
- explicit *support for local services* within the village that can be autonomous relative to a national carrier;
- *novel power/coverage trade-offs* based on intermittency that can provide bursts of wider coverage; and
- a *portfolio of data and voice services* (not just GSM).

VBTS is essentially an outdoor PC with a software-defined radio that implements a low-power low-capacity GSM base station. Long-distance WiFi provides "backhaul" into the carrier. At around 20W, its power consumption is low enough to avoid diesel generators and the corresponding requirement for roads and fences. This also reduces the operating costs significantly. The base station can be deployed in the middle of the village, on a nearby hill, or in any other area with line-of-sight coverage.

Although much of the contribution of VBTS is engineering the combination of a software radio, WiFi backhaul, and local generation, we foresee two main research contributions: 1) the development of a platform for a wide range of services, and 2) the optimization of coverage versus power consumption via variable power and intermittent coverage.

We investigate these benefits and requirements in more depth in this short paper.

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2. OFF-THE-GRID

Given the limits and costs of power, we first require that VBTS operate totally "off the grid". This simplifies the provisioning of network coverage in areas that are currently neglected by carriers.

There are many pieces to operating "off the grid". First, VBTS must be able to operate without any grid power, as power is often not available or of low quality in the developing world, potentially damaging equipment [2]. We propose operating the entire base station on solely wind or solar power, which removes the need for diesel generators, as well as the implied diesel, roads, and refueling trips. The key to this is to lower the required power by an order of magnitude (from 100s to 10s of watts).

Second, though there are examples of base stations that support just local calls [3], we intend to connect users to the global phone system. Doing this requires a connection to the outside world, the *backhaul*. For high-density areas, this is often a wired connection supporting a large number of users. For more distant deployments, carriers utilize a high-bandwidth microwave link (approximately US$20K). These systems are unsustainable for rural areas, due to the limits of range and cost. We propose leveraging recent advances long-distance WiFi [4] to provide the necessary backhaul.

3. LOCAL VS BACKHAULED OPERATION

A key point in the design of the village base station is defining two tiers of service: local and backhauled. Backhauled services are those that require backhaul bandwidth and interaction with the carrier, such as phone calls outside the village and access to the greater web. These services have both higher inherent costs and more limitations, as they need to "play nice" with the carrier's network.

Traditional cellular systems require access to centralized servers for normal operation, such as the Short Message Service Center for SMS. This means that all calls and texts require an active backhaul link, an expensive limitation. VBTS avoids this by allowing for *local-only* communications. As the base station is a full-featured private branch exchange (PBX), local calls can be made without backhaul bandwidth and without the involvement of the carrier, at much lower cost. This advantage covers data services too, as we can cache data on the local PC to minimize off-base station requests. These services have essentially zero operational cost until the base station is over-utilized, as there is no marginal cost for the bandwidth or the power.

Local services are autonomous relative to the carrier and thus have greater flexibility; it is easier to deploy a new local service than a new carrier-wide service. This autonomy enables both entrepreneurs and researchers to experiment with new services.

Examples of local services include local calls and SMS (within the village), voice-mail storage, and support for local content such as news, audio social media [5], and web caching.

4. INTERMITTENCY

In our prior work [6] we found that users optimized their network usage to deal with intermittent connectivity. We utilize this fact and offer intermittent, rather than consistent, coverage. Intermittent coverage allows us to lower our duty cycle and reduce the power consumption of our infrastructure. We use this saved energy to provide a wider *total* coverage area.

We note that the particular duty cycle used is configurable. For instance, in an area of comparatively high density, it may be economically feasible to provide more consistent coverage over a smaller area. If there is low density, we may choose to be highly intermittent and cover a much wider area. This trade-off is essential to covering the many differing conditions in the developing world.

There are a number of other factors possibly involved in determining the duty cycle. First, antennae and amplifier properties will dictate the trade-offs available. Highly directional antennae could provide "hot-spots" of network coverage, while varying amplification will allow variable range. There are also many usability issues. For instance, it would be foolish to reduce the coverage while a call was in progress or during important market times. Lastly, we may wish to increase coverage during emergencies, perhaps to send warning SMS or provide information to medical staff. Coordinating coverage with the handsets themselves is likely the trickiest part of utilizing intermittency, as the handsets could waste a large amount of power scanning for network.

5. SERVICES

As the village base station is not just a GSM device, but a complete programmable computer, we can provide significantly more value to rural users than traditional GSM deployments. We believe that there are a wide variety of base station applications that would benefit rural users, and we explore a few in more detail.

Voice: Audio services have been viewed by many as the "killer apps" for developing regions. They require no translation, are intuitive to users, and do not require specialized phones. Lastly, voice applications have the lowest literacy bar; only speech is required.

VBTS provides the perfect platform for these sorts of applications. The content is inherently local: topics such as education in the community or farming practices relevant to the local crops. In fact, research has shown that highly localized content can be more effective for influencing practices [7]. The technology itself also eases the difficulty in implementing such a system: every VBTS includes standard PBX software.

As an example application, we previously proposed using *voice messages* as a primary communication medium [6]. We showed that this would allow for better tower utilization, be easier to use, and be cheaper for both network providers and users. VBTS allows for an incremental deployment of this technology. Voice messages can be sent and received locally, and converted to MMS for delivery outside of the local network.

Quite a few other projects utilize the power of voice among rural users. They range from supporting agricultural workers [5] to teachers [8]. These voice applications generally use a PBX to provide something resembling a "voice message board" where users can share ideas, voice opinions, and listen to expert advice. VBTS simplifies this by providing a simple, central place to organize and operate such a system.

Data: VBTS also provides a compelling environment for data-centric applications. These apps have often been hindered by high costs, low bandwidth, and a lack of end-to-end connectivity. The VBTS platform will mitigate these concerns.

The first issue for any data service in a rural area is dealing with poor connectivity. This fact is exacerbated by our desire to utilize intermittency to lower power requirements. We plan to utilize delay tolerant networking(DTN) [9] to mitigate some of these concerns. DTN is a store-and-forward architecture designed for challenged networks, and provides a framework for operation in these areas.

Storage in the developing world is highly related to network connectivity. Moving data around is expensive, and as such it is extremely difficult to maintain any consistent data model. There are solutions to this, such as TierStore [10], which simplify shared-data applications such as e-mail and content distribution.

VBTS will allow for distributed storage, minimizing the use of the backhaul connection. However, the use of local applications will also ease the storage task. For example, if a user wants to share a picture across phones, it need not be routed to a central message server; instead it can be stored locally on the base station itself. This reduces the bandwidth needs and provides better service.

6. CONCLUSION

In this position paper we introduced the concept of the *Village Base Station* (VBTS), a GSM base station designed to be deployed "off the grid" to locations without power or network infrastructure. VBTS will also benefit rural users in other ways. First, the base station will provide a wide portfolio of voice and data services. This will encompass recent advances in user-generated content, distributed caches, and other highly localized services. Secondly, we explicitly support *local* services, and attempt to minimize the need for backhaul and maximize the autonomy of the local services relative to a national carrier. Finally, we use *intermittent coverage* to provide power/coverage trade-offs to users and operators.

We believe this approach can greatly improve the viability of network coverage for the billions of rural users who are currently unserved. Our base station is economical and optimized for areas of low user density and limited infrastructure. We hope that presenting this early version of the work to the research community will improve the Village Base Station.

7. REFERENCES

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