BOSNet: A Municipal LoRaWAN Mesh

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***Abstract*—After careful evaluation of several possible protocols and mesh configurations for a possible open mesh system for the Cambridge/Boston location, the authors propose a novel city-wide network that culls from the best practices of low-power wireless practitioners, many of them validated in earlier projects by the University consortium local to Boston. It is planned to be passive, opportunistic, and leverage existing infrastructure where available. The novelty will be based around the bridging functionality of tried-and-true wireless technologies: IEEE standard WiFi and LoRaWAN. This paper presents a description of the service and potential use cases.**

***Index Terms*—Practical Experiences, Low-Power, Mesh, Wireless, LoRaWAN, Infrastructure**

I. Introduction

In the early part of the century, there was a broad interest in using WiFi to engage students intramurally across campus (and municipalities) and untether them from Ethernet. While there was an exploratory component to this, colleges with thick granite walls or constraints on construction often preferred the adoption of wireless networking hardware to drill and run RG-58u cable or Cat5e cable. Schools like West Point, with their 3-foot thick walls in their academic buildings, had few wired options [1].

Boston area schools were in a similar fix when the demand to allow students to roam increased as laptops replaced desktops in many classrooms. However, WiFi is not without constraints of its own. Deployments are subject to interference and noise, power consumption, and more. Such demand for new non-wired connectivity naturally led to exploring wireless networking options and developing and implementing various mesh solutions in academia.

II. Mesh Systems

Although mesh networks have yet to be universally adopted or standardized, there are a multitude of options, both open and proprietary. Building up each of the various stacks involves selection of hardware and protocols, optimizing some aspects at the cost of others. While a definitive evaluation is not likely possible and certainly out of the scope of this paper, several comprehensive reviews have previously been completed [2]–[4]. It should be noted that any evaluation is time-dependent and will become less accurate as implementations, specifications, and ecosystems evolve.

Regardless of mesh section, for many use cases, the need exists for a publicly fielded network. Two such use cases are public access in smart cities or for cyber-physical systems (CPS) [5], [6]. Such project often uses sensors and actuators and may require passive, non-interactive access to dynamic or static infrastructure and objects.

A. Muniwireless

Many of the basic ideas in wireless mesh networking in its application to the growing call for "Municipal Wireless" were first developed for University use. MIT Roofnet has a long pedigree of using derivatives of routing protocols from prior research in mobile ad-hoc networking (MANET). Many research groups maintain wireless testbeds on which to evaluate the real-world performance of MANET protocols. Several community wireless mesh network efforts still exist, such as Seattle Wireless. Since the advent of commercial firms like Meraki, Tropos Networks, and Mesh-Networks Inc., we have now seen subscription services in this space. Many of these mesh nets use directional antennas and the Open Shortest Path First (OSPF) routing protocol. This approach works well for relatively sparse networks, whereas MIT Roofnet targeted future networks with high user density. Sensor networks use multi-hop wireless networks to collect data and thus face problems similar to Roofnet. A signal strength map of Roofnet circa 2005 is shown in Figure 1.

Some municipalities, notably Philadelphia, PA, have attempted city-wide coverage through a partnership or outsourcing to large Internet Service Providers (ISPs) [8]. Although now defunct, the Wireless Philadelphia project may have been ahead of its time. In contrast to that, Boston and Cambridge

Special thanks to the past mesh project collaborators and to Odysseus Project and others for letting us use their figures.

Fig. 1. Roofnet signal strength map circa 2005 [7].

rolled their fielding out internally. Among other innovations, they offered non-beaconing SSIDs for all of the Universities so that if your laptop was registered with a particular school your MAC address would already be cached in the DHCP pool, and their respective institution handled security. This approach preceded the advent of Eduroam, and, indeed, might have influenced its design [9], [10].

Since these early days of mesh design, sufficient changes have happened, especially in the area of wireless security. Some of these advances at the time would now be considered naïve. Indeed, MIT, after having supported a "whitelist" public WiFi service for years, has recently gone to a capture portal system which other Universities have long enforced.

Furthermore, since it was a city-wide network, a given access point would have a full Class C IP address subnet to cull from that would be recognized at all the other Access Points (APs) on the service. Thus, due to the stateless nature of TCP / IP, one could drive down Massachusetts Avenue and never lose connectivity. Of course, this is not that impressive nowadays, but back then, when there were few mobile mesh options, that was a novel feature set.

B. Odysseus

Odysseus is a deprecated Boston University (BU) project that established some of the security best practices for our various local wireless network efforts. While we did not test Zigbee functionality in any of our Alpha tests, our projects take a lot from the security model used in Odysseus. Some of the design for the Odysseus Project is shown in Figure 2.

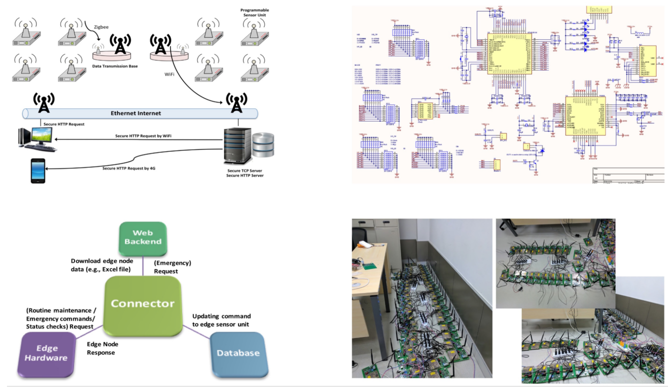

Fig. 2. The Odysseus Project used commodity nodes to route uninspected packets to a head node for analysis [11].

C. IoTNet

MIT and BU have alpha-tested services which fall under the umbrella of projects with the working name IoTNet. These services purported to bridge a passive interaction to an app. It leveraged meshed-based services much in the same way Roofnet and Cambridge Public Internet (CPI) leveraged Location Based Services. It should be mentioned that along with Cambridge's CPI program, Boston and many other cities now have public WiFi. Coverage of CPI and Boston's plan for free WiFi are shown in Figures 3 and 4, respectively.

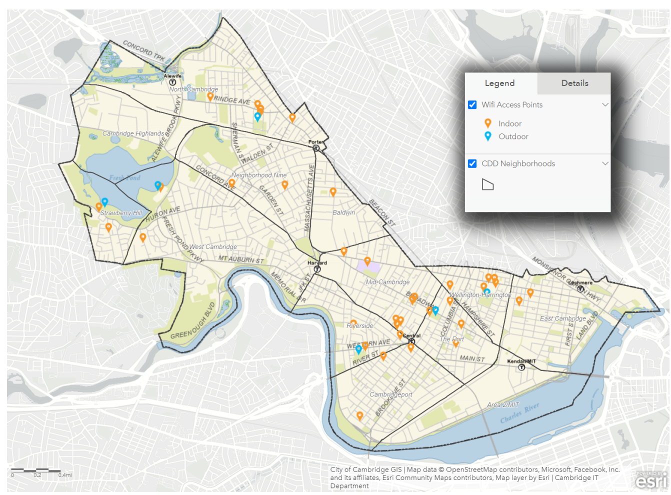

Fig. 3. map of CPI. Stitched from interactive online map available from https://www.cambridgema.gov/departments/informationtechnology/cpi . *Website's legend has been moved to make it more readable for print.*

IoTNet used much of the same fielding model as Roofnet in its local tests. A student would receive an IoTNet node to keep and use how they saw fit as long as they kept the board

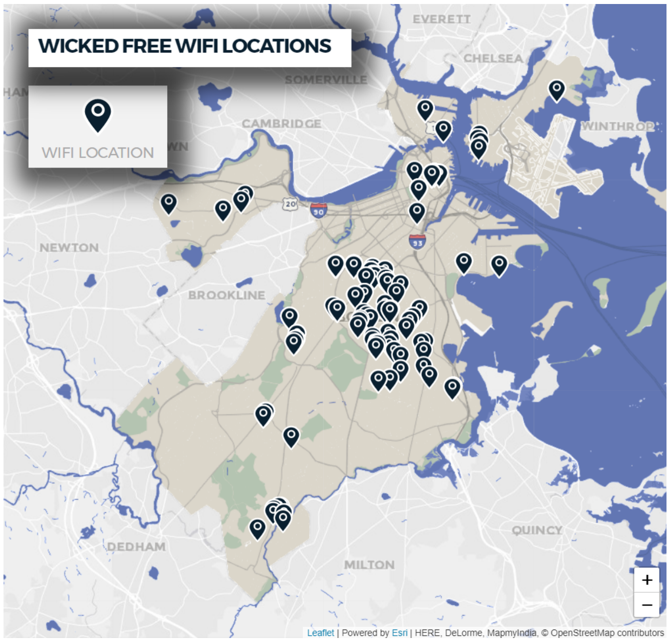

Fig. 4. Similar map is available from Boston for public WiFi. Stitched from interactive online map available from https://www.boston.gov/departments/innovation-and-technology/how-wicked-free-wi-fi-works#map--262256. *Website's legend has been moved to make it more readable for print.*

powered up and near a window. If the student wanted (free) Internet, they would just power the device up. Devices could optionally be configured to bridge to Ethernet with a specially configured network stack for system analysis. This allowed the researchers to employ what was termed an AMOS model; Agnostic Mesh / Omniscient Spoke. Commodity nodes were field where needed, and the prosumers and system administrators emplaced nodes where needed (in bandwidth deserts).

IoTNet primary feature set includes the routing from arbitrary input to ad hoc output by saturating an area with LoRaWAN coverage. While sub-optimal bandwidth and latency, the underlying LoRa component of the stack ensured long range accessibility.

IoTNet is not a best-effort real-time network but can guarantee delivery by using opportunistic routing protocols. This is done by using stack selections such as WiFidonet. This is yet another feature that our researchers inherited from the MIT Pervasive and Ubiquitous computing initiatives. In an effort to ensure sustainability some initial work has been done on powering various components, as can be seen in Figure 5.

D. The Things Network

IoTNet is compatible with The Things Network, which is the leading public LoRa provisioning service in the world [12]. The beta network is registered at http://thethingsnetwork.org/c/boston and allows users to join the network by bringing their personal hardware. There are many DIY gateway designs listed at their gateways site (www.thethingsnetwork.org/docs/gateways), and we implemented the fully compliant variety.

Fig. 5. WiFiDoNet windmill designed to power WFN Router / Bridge [13].

III. Project Design

TABLE I
COMPARISON OF LOCAL MESH PROJECTS

	Muniwireless	Roofnet	Odysseus	IoTNet
Academic Support	1	4	3	2
Government Support	4	2	3	1
Industry Support	4	3	1	2
Availability	2	4	3	1
User Acceptance	2	1	4	3
Sustainability	4	1	3	2

A. Motivation

The motivations for the work are multi-fold. The authors believe there is a demand for a passive interaction device that makes repetitive, predictable actions automatic. We have reviewed the various previous projects in six dimensions we believe are important for a successful mesh deployment and rated each from one to four (higher being better), shown in Table I. We believe that by addressing these six stages we could improve facilitation of mesh adoption. We believe that BOSNet could address each of these. These stages are:

1) ”Academic Support”: Giving legitimacy to lab quality project through extending implicit and explicit support.
2) ”Government support”: Limiting red-tape regulation, thus empowering the project to safely be adopted with city-level support being sufficient.
3) ”Industry Support”: Ensuring that there is vendor non-competition, leading to a safe harbor for innovation.
4) ”Availability”: Providing access to both hardware and software, with ease of use and documentation.
5) ”User acceptance”: Having a good project perception by users, leading to actual adoption of the new technology.
6) ”Sustainability”: Ensuring there is sufficiently planned upkeep and maintenance with reasonable project closure and hand-over as necessary.

There are many opportunities in daily life where one's activities are scriptable. For instance, when one stands in front of an elevator, it is usually because one wants it to come to them. Until entering the elevator and selecting a specific floor, the initiating task of requesting service is often implied simply by the user's presence. Thus we can at least remove the gratuitous call button press. It is expected that our device and network will eliminate false negatives, and while it may result in a couple of false positives every year, there is essentially no cost to those. No more than those offered by the status quo. However, when implementing any automation, it is essential to attempt to pre-emptively determine its specific risk and safety concerns, if any, ahead of time where possible. In the case of an elevator, that might be summoning service when not needed - something that already happens when a user presses the wrong direction or when the user changes their mind and rescinds need while walking away. In this last scenario, such a solution may offer a new remedy by allowing the request to be canceled when the user's proximity exceeds a threshold (e.g., the user walks away).

The value to this approach should be obvious. There are very few free wireless access points anymore, and most users are advisably wary of them. A Man-in-the-middle exploit is terrible enough, but logging on to an unknown network just for convenience's sake is reckless and predictably not in practice. But with our network approach, a user can get on their own network and potentially their own printer.

Many Universities are going to name-based networks and eschewing DNS. For instance, MIT has sold off large swaths of its Class A and gone to a fully NATted network, so while a user could have gone to http://18.21.11.11 to get to http://ttn.mit.edu/ one can still get there, although it now has an IP address that begins with a 10 (Net10 is non-routable so a user will see the address from the MIT router that it received its address from).

B. BOSNet

The authors propose to extend this concept to its natural conclusion. Many mobile network users will tell you they are resigned to carrying two consumer electronics devices. At least for medical wearables, this may be in part a compound decision based on several factors, such as its effect on health expectation, the perceived ease of use, and the social influence associated with the additional device [14], [15]. A cell phone, for sure, will be one of them. And the second device could be an Apple watch or similar device, which would pair via Bluetooth with the device from which you get your (4G or 5G) backhaul service or possibly another business vanity option, like a reimagined ring.

We offer another alternative. A hard case for your phone after the fashion of Otterbox. Our suggested case would contain a LoRa radio that would communicate with your phone via NFC. There are a couple of commercial entities approaching this space, but they require specific phone models. We have tested this on several Android phones and it works well enough that we are looking to mass-produce it. An Apple phone version will also be considered eventually. This approach will now allow individuals to passively interact with LoRaWAN access points like TheThingsNetwork beacons just through the facility of proximity. If the phone did not have another radio, there would be no way to do this with just the equivalent of a ping. A pairing request on Bluetooth does generate some metrics, but not consistently enough for the messaging to be reliable.

The advantage of this network is that it inherits much of the value of the networks that preceded it. It is not owned by anyone in particular. Commercial entities can participate if they want too much in the same way that internet backbone routers carry packets that are headed off-site. Indeed, that is one of the founding principles of the Internet. A device manufacturer will route your packets if you do the same. That is fundamental to the basic IEEE specifications of routed, DNS, bind, etc.

We plan a new design for the Access Point / Router which we will make available to willing participants in the initial test area, much as we did with the first revision of the IoTNet board. The base station providers will be incentivized by a combination of earning "coins" for the community use of their systems as well as a client/server screen saver program we plan on testing. This screen saver is more of a daemon with a low nice level that watches CPU load and kicks in when the board is not in use. This will be similar to the many @HOME variants (Einstein@HOME, GIMPS, and SETI@HOME for instance). We believe the combination of these offerings will incentivize both the provider and the consumer of this infrastructure. You don't have to be a member to provide access, but you will want to use it, so if you set up a board anonymously, that will be helpful to both yourself and, to a greater extent, BOSNet users in the vicinity. Regarding the client device, we have prototyped a radio that fits into a hard shell case for your cell phone, much like those made by Otterbox. It conveniently communicates to your phone via NFC, which was placed next to it. We plan to run tests on power draws to see if this is worth the tradeoffs.

A usage case will play out like this. Potential users of our network will have at least two radio devices on them. That registered user will come into one of our BOSNet Hot spots. We will be able to tell where the user is located within a couple of centimeters. Our system will send a directive to one of our pro user access points, and it will point a directional antenna at the user to be able to provide service http://web.mit.edu/~kkeville/www/ephemeris/. At that point, you will have a secure point-to-point network that you substantially provisioned yourself through your dashboard. The team has also investigated power provisioning issues since there is a hard functionality gap between indoor and outdoor BOSNet nodes. Indoors, owners are incentivized to provide their own power considering the rich feature set functionality they get in return. Outdoor nodes usually do not have easy access to power and usually require negotiation of Rights-Of-Way. In Boston, we have investigated these issues during previous installations. Using our AMOS model, we have placed beefy routers at places with Non-penetrating Roof Mounts (NPRM) or localized power generation, usually solar panels. One of our installations used a Savonius windmill to generate the necessary power to keep the WAP online. Analysis of the node's performance is left for future work.

Notes

Figure 2 are used with permission. Figure 5 is from a previous, unpublished write-up.

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