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Community Networks for Resilience

About the Author

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About New America

New America is a nonprofit, nonpartisan public policy institute that invests in new thinkers and new ideas to address the next generation of challenges facing the United States.

About Open Technology Institute

The Open Technology Institute strengthens communities through grounded research, technological innovation, and policy reform. We create reforms to support open source innovations and foster open technologies and communications networks. Partnering with communities, researchers, industry and public interest groups, we promote affordable, universal, and ubiquitous communications networks.

Introduction

As consumer choice in the broadband market has declined and the need for more resilient infrastructure has increased, community wireless networks are increasingly important tools for local communications, economic development, and for access to critical information. OTI has developed an approach to planning and building these networks that uses technical and social processes to increase their resiliency. This paper presents "blueprints" for some of these designs, so other communities have a starting point for their own network planning and organizing.

Neighborhood networks designed for resilience and disaster recovery must be planned, built and maintained by the communities they intend to serve in order to ensure they are tailored to the needs of the community, and that individuals in the communities are able to repair the networks during or after emergencies. Participatory planning or co-design methods are crucial: only through collaboration among anchor institutions, small businesses, local organizations, and individuals can the network best serve the neighborhood. The result will be that everyone involved will be better prepared for emergencies and for restoring the network when it is most needed. Network stewards and trainees, additional backup service options, cooperative bandwidth purchasing, and the option of public Wi-Fi coverage all enhance the resilience and economic benefits to small businesses, organizations, and individuals that work together in vulnerable areas by ensuring the availability of resources needed to maintain and troubleshoot the networks.

Such networks should be designed with the following key intentions:

- **Social Resilience - A team of neighborhood Digital Stewards [1] should be involved in the planning, design, and installation of the local network. This facilitates the maintenance and recovery in a disaster or emergency situation, and increases the long-term sustainability of the network.**
- **Local Communications - The network is designed as a local area "intranet", able to provide services and connect neighbors even in the event an Internet connection is unavailable.**
- **Redundancy by Design - The network design should minimize points of failure. Wireless equipment should be high quality and require minimal electricity so it can be powered by batteries or other backup power sources for long stretches of time. The network can - and should - use many small, low-cost devices rather than fewer, higher-priced ones. This redundancy should extend to multiple connections to the Internet, backup power sources, and multiple connections between sites.**

These social and technological features are helpful for resilience, but they are only one element in designing and maintaining a local network. Organizing local residents, designing a community governance structure, ensuring the sustainability of the network, and planning for an eventual disaster are all vital elements in network design for resilience.

SOCIAL RESILIENCE

Digital Stewards

A resilient local network includes a neighborhood training program that ensures the local community has the skills and resources to repair or reconfigure the network following a disaster and for everyday needs. OTI has worked with communities in Detroit and in Red Hook, Brooklyn, to develop a practice of "Digital Stewardship" to facilitate the visioning, construction, and maintenance of networks. Resident "Digital Stewards" engage the community in the planning of the network, conduct new installations, and perform technical support and maintenance. They can also serve as a neighborhood communications response team, to prepare for and respond to disaster.

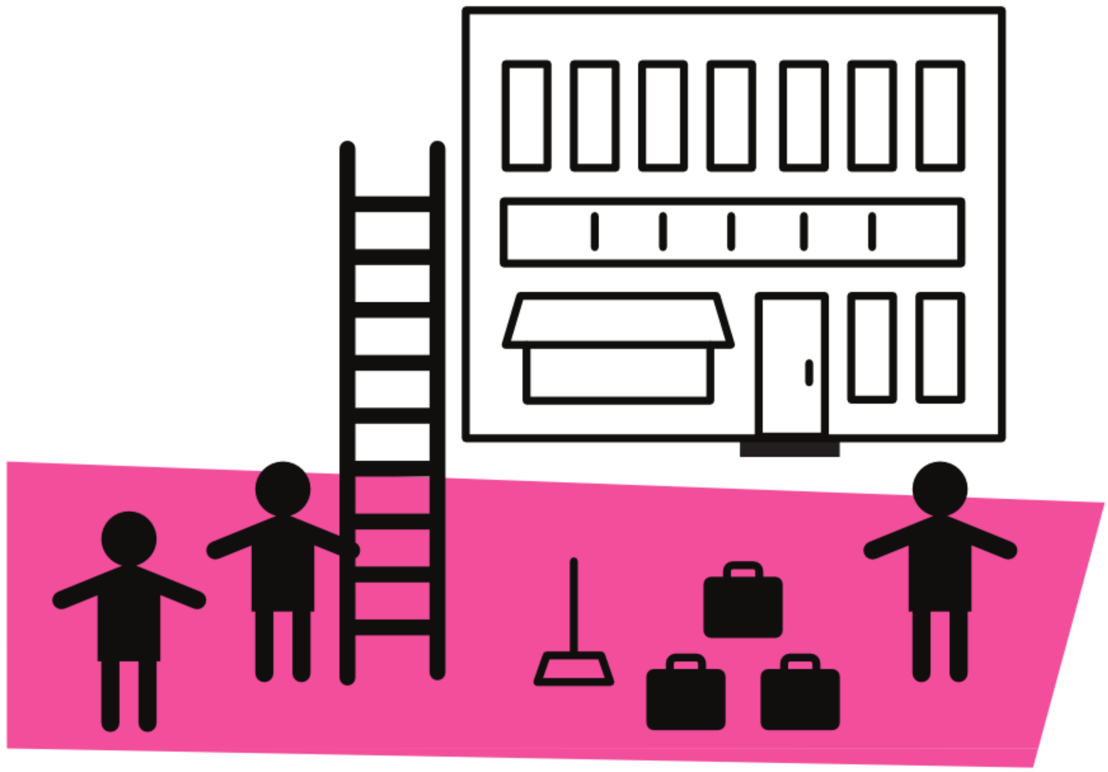
Stewards are usually already present in a neighborhood. Typically, they are individuals who have a commitment to the neighborhood and a desire to learn and build new things. They should have at least one of three core competencies for network construction: community engagement, network administration (or a related technical background), and equipment installation.

Stewards can teach basic networking skills to residents, small business owners, and other people that may be impacted in the event of a storm or other natural disaster. To help Stewards engage with their communities, OTI has created the Commotion Construction Kit [2]: a modular set of instructional materials with accessible graphics and hands-on activities for users of all skill levels. These are very useful in the intentional, participatory design and deployment of local networks. The toolkit includes active-learning modules on participatory planning, site assessment, software configuration, installation and troubleshooting. These materials are designed for a collaborative approach to network construction that engages all members of the community.

The Stewards learn to build networks as they go through the organizing and installation process. They begin with participatory planning activities, surveying groups and individuals in the community, surveying buildings and sites for installations, and using maps and online tools to envision the network. They then start with high rooftops or anchor institutions and build a high-level backbone for the neighborhood. This enables interconnection between disconnected sections of neighborhoods, or areas that may not have direct line-of-sight. In addition, these backbone sites should be fortified with higher powered routers, a robust backup electricity solution, and solid and secure mounting hardware.

Network governance

The most important part of any community technology project is the people. This document focused quite a bit on the technical details of specific site designs, hardware, software, training models and so on - but the most challenging and interesting part of these projects is the community



organizing process used to determine how the network will be run: the governance process.

Local networks will (hopefully) have many users - and healthy networks should have many people participating in the decisions on how to run the network. If a network is sustainable and growing, questions will come up about where to add coverage, how to share costs, and more. If individuals or institutions are hosting equipment for the network, they will have expectations on how it should work, and what sort of support they will need from the Digital Stewards.

In addition, some users might not always behave themselves on the network. The Internet has lots of opportunities to download content that may infringe on copyright, take up lots of bandwidth, or even be illegal. Questions will come up about what the community should do when one of the users of the network decides to go down one of those paths. Should the Digital Stewards handle those issues? Are those people banned from the network? Should the network filter content? These questions are also part of a governance process - which is something each network will develop over time.

LOCAL COMMUNICATIONS

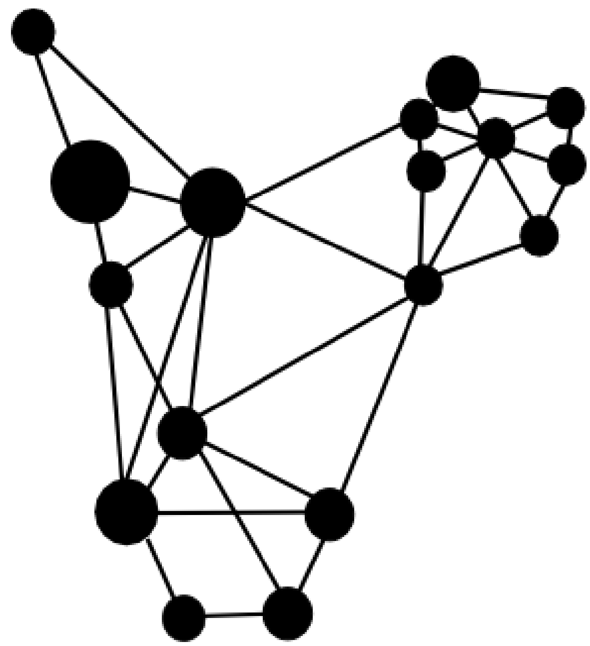
Mesh Wireless

Wireless technologies such as Wi-Fi are an essential tool for community networks: they are low-cost, easy to install and use, and can be license and right-of-way free. For the purposes of this paper, we are focusing on wireless technology, but still believe that communities should consider wired backbone networks, microtrenching local fiber optics, community computer centers, and other technologies as important options in "do it ourselves" infrastructure.

Wireless technologies are used in many Wireless Internet Service Provider (WISP) models around the world. Most use traditional wireless architectures such as Point-to-Point (connecting two sites), and Point-to-Multipoint (connecting many sites from a single tower, similar to cell-phone networks). These are proven methods for building wireless networks. Another tool for resilient wireless networking is mesh networking, a technology for creating inexpensive local networks that allow users to connect their devices directly with each other rather than going through a central hub. Unlike a series of wireless hotspots, a local mesh works as a network whether or not it is connected to the Internet.

The use of mesh networking technology can further enhance the resilience of a local network, due to the following key characteristics:

- **If some nodes in the network are damaged or disabled, mesh nodes will dynamically route traffic around the outage.**
- **Every mesh node shares the responsibility of routing traffic.**
- **New devices or connections to the Internet can be added anywhere in the network, extending and strengthening it.**



The Open Technology Institute (OTI) developed Commotion Wireless [3], an open-source toolkit of software and instructional materials, to facilitate participatory deployment of resilient and decentralized mesh networks.

A Commotion-powered network can distribute an Internet connection across a wide area; users connect to it with their computers or smartphones as they would any Wi-Fi access point. Within the network, the mesh software determines the optimal route to the Internet, dynamically adjusting if one connection goes down. Users or administrators of the network can add new nodes on an ad-hoc basis to expand coverage or meet changing needs. The network can also function as a self-contained "intranet" with local content and applications, so even if the neighborhood is completely cut off from the Internet, neighbors can still communicate with each other.

There are a variety of mesh solutions available. Commotion, LibreMesh [4], Mesh Potato [5], Freifunk [6], Guifi.net [7] and others are all open source solutions. These platforms do not rely on a management solution in the cloud, so all of its features are available regardless of Internet connectivity. Like many mesh solutions, the Commotion Router package is built on top of numerous open-source software packages, including OpenWRT [8] and Serval [9], so there is no licensing fee. The software is designed to replace common router operating system "firmware," such as AirOS on Ubiquiti [10] AirMax devices, to enable mesh networking capabilities. The mesh routing protocol used by Commotion is the Optimized Link State Routing protocol [11], and allows the mesh nodes to route traffic and add new nodes dynamically.

The Commotion software is designed to automatically configure as many parameters of the mesh network for the user as possible. After installing the firmware on a router, the user runs a "Setup Wizard" with a graphical user interface to name the node and assign it a password for the network, which creates secure connections among the nodes, user access points and IP addresses. Each device uses the OLSR routing protocol to find its neighbors within the wireless broadcast range and automatically connect to them. Once these connections are formed, the devices route connections through any device participating in the network. If an Internet connection or local application is available on the network, each node advertises those services and users can connect to them right away.

The Open Technology Institute released Commotion 1.0 at the beginning of 2014 and continues to improve the software and construction toolkit. The Commotion software is available for free to anyone under the GNU General Public License. OTI incorporates other wireless components into our networks, as appropriate. These may include other mesh elements, point-to-point links, and point-to-multipoint links where these provide added stability or resilience, or otherwise meet the specific needs of the host community.

Local network servers

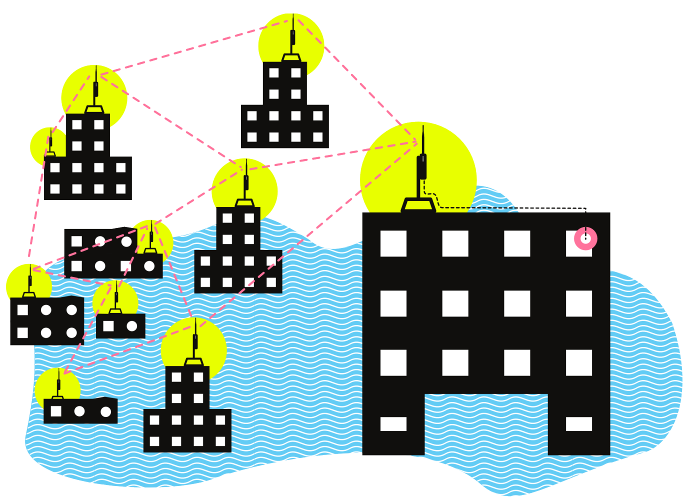
We recommend each network have at least one server that provides local applications, such as text chat, a message board, etc. to all users on the network, without the need for an Internet connection. The server can support additional local applications based on the needs and capabilities of the community as well. These can support community communication and sharing year-round, but also provide valuable connections during disasters.

Distributed Internet gateways

An Internet gateway is the connection from the local network to the global Internet. Networks should incorporate multiple gateways, if possible. Mesh networks are designed to share resources on the network equally, but a single gateway may become overloaded in a busy network. A wireless node's proximity to any gateway will impact the speed and reliability of the connection to the Internet. A number of gateways with a moderate amount of bandwidth (for instance, a 25Mbit download / 5Mbit upload speed) distributed around the network will often work quite well. If these can be obtained from multiple service providers, this adds an additional layer of redundancy and resilience to the network. If any site still has a connection to the Internet after a disaster, or if emergency responders can bring in a satellite or long distance terrestrial wireless connection, then the rest of the mesh should be able to connect to the Internet.

It should be noted that many major Internet Service Providers have restrictions on how their connections can be used. Sharing connections between neighbors or individuals outside of a single household is often forbidden by the terms of service (though not illegal). We believe that these restrictions should be suspended during emergencies, and that communities should advocate for exceptions to these rules with their municipalities.

To avoid complications with some ISP's terms of service, it is recommended to work with a local ISP that may not have such restrictions. Even if local ISPs do have such restrictions, they are more likely to speak to you about exceptions or flexible options for connections to the local network. Otherwise, neighborhood networks will need to purchase dedicated (non-consumer grade) ISP Ethernet connections. Often called "Dedicated Internet Access" or "Metro Ethernet", these connections have very high availability and symmetric bandwidth, but the cost can be much higher than similar speed consumer connections. Digital Stewards will need to assess network performance and need at regular intervals to scale the number of Internet connections and available bandwidth throughout the network.

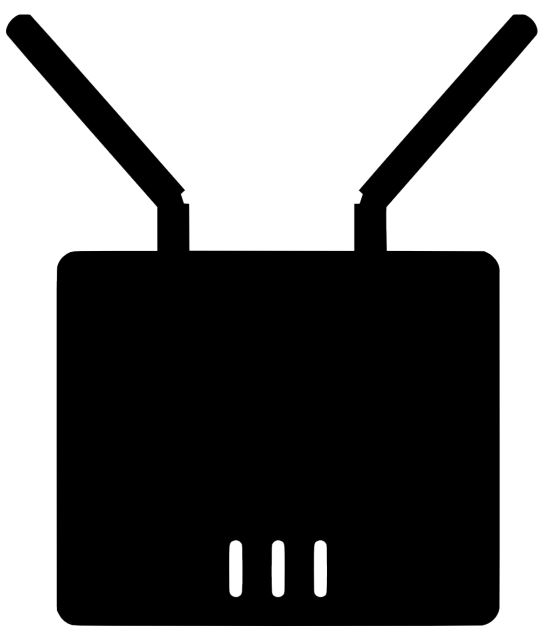


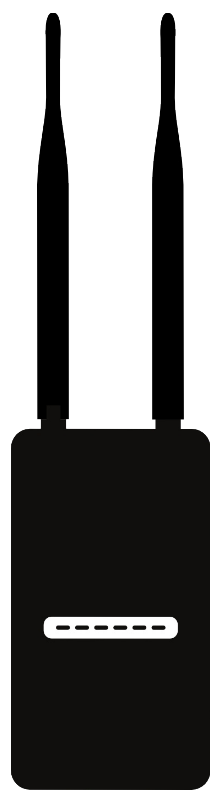
REDUNDANCY BY DESIGN

Hardware

A wide variety of hardware can be used to build resilient networks - OTI does not endorse any specific manufacturer. Currently, the Commotion router software works best on Ubiquiti AirMax and UniFi equipment, but development is underway to support more routers. Even if you are not interested in mesh technology, the site designs shown below should provide helpful ideas for making every neighborhood network more resilient. Regardless of what hardware and equipment is used, every network should be designed to minimize points of failure, and allow those failed devices or sections of network to be quickly modified or repaired.

Resilient networks can - and should - use many small, low-cost devices rather than fewer, higher-priced ones. The Ubiquiti Airmax line of routers have excellent build quality, reasonable cost, and considerable range (depending on any physical obstructions and radio interference). Most models are rated for outdoor use, and the equipment is consistently proven and used by Wireless Internet Service Providers (WISPs) worldwide. The typical device draws approximately 10 watts of electricity – about the same as a digital alarm clock – and can be powered from the grid, with solar panels, or with battery packs.



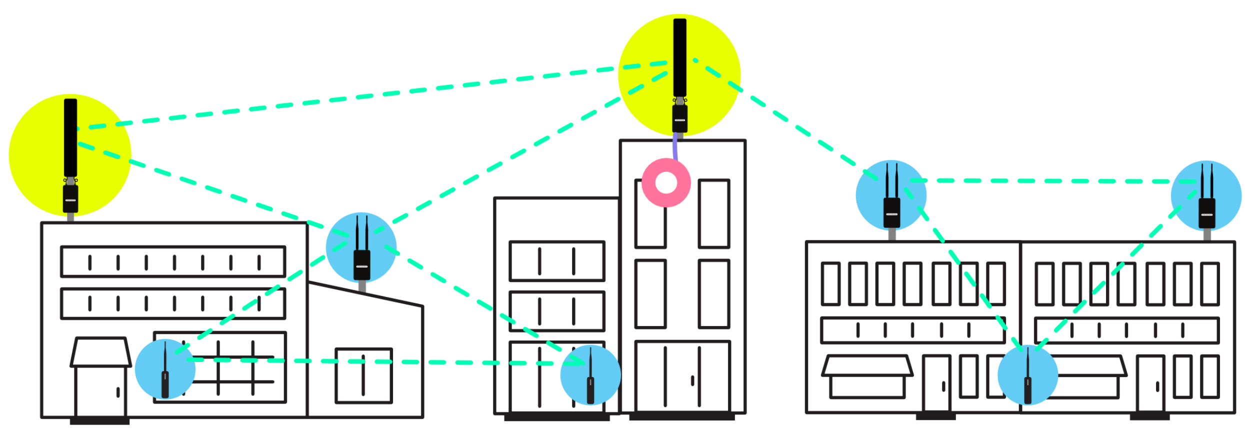


Network Site Blueprints

The diagram below shows the different installation types and an Internet gateway in combination. A network can be constructed with any combination of these installation types, but this architecture balances coverage, stability, resilience, and ease of installation.

There are four types of sites:

- **Anchor institutions** - Usually a very high or the highest point in the neighborhood. Interconnect other rooftop network sites. Made up of powerful mesh equipment, with a robust power backup system.
- **Rooftops** - Provide coverage to areas of the neighborhood, and interconnect with other rooftops and anchor nodes. Made up of omnidirectional mesh nodes, with Uninterruptible Power Supplies (UPS).
- **Window installations** - Extends the network to the street and can provide some indoor coverage. Omnidirectional or directional mesh nodes, with UPS as an option.
- **Portable Mesh Kits** - These take the place of rooftops (or anchors) during an emergency, intended for installation after a storm or disaster. These contain an omnidirectional mesh node, battery packs, a waterproof enclosure, and a portable mount. A portable solar charger is optional.



Internet Gateway
Connection to the global Internet or point of presence, such as a point-to-point wireless connection or fiber-optic backaul.

Wired connection

Wireless connection

Anchor Nodes
Mesh wireless nodes with longer reach.

Rooftop Nodes
Omnidirectional mesh wireless nodes placed for user access and mesh links.

Interior Nodes
Omnidirectional mesh wireless nodes placed for user access.

This installation architecture – interior access nodes, rooftop distribution and access nodes, higher-power anchor nodes, and distributed gateways – can scale from small block-sized networks to large neighborhoods, and can adapt to shifting needs in each area based on economic or environmental conditions. Below are details on the elements that make each site unique and important on the network. These are just models, they can and should be modified and improved for your neighborhood or community use case.

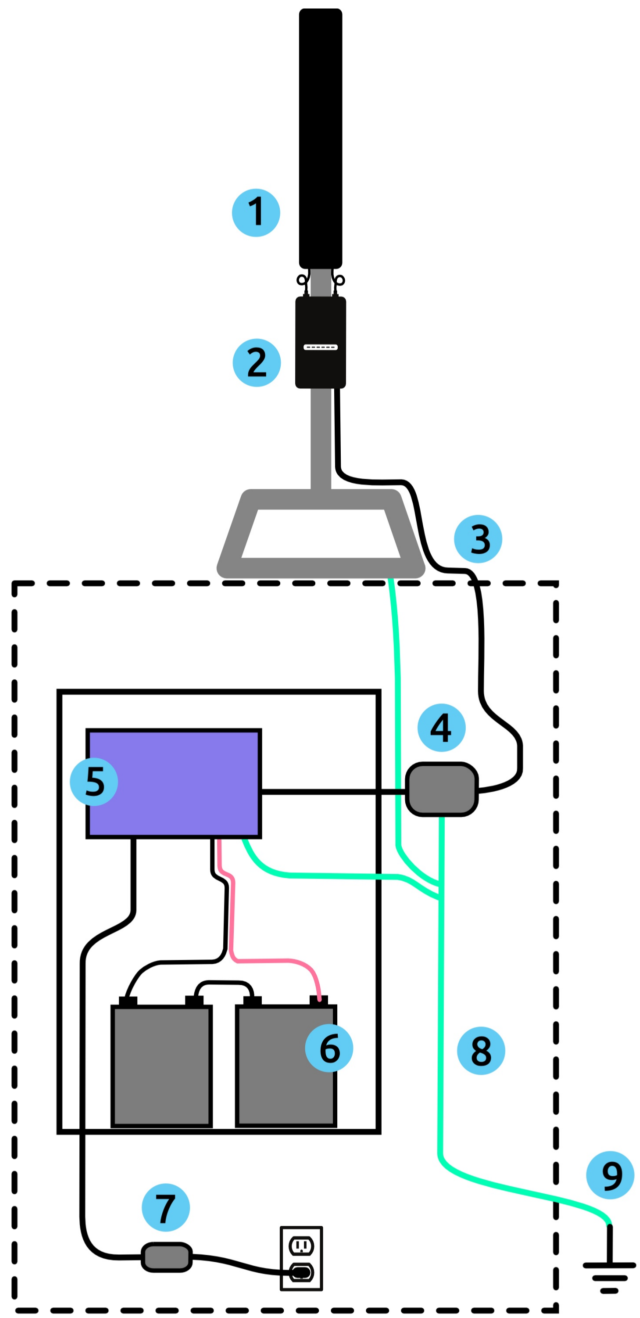
Anchor Institutions

Most neighborhood networks will need at least one node that provides greater reach than the rest. This can extend the coverage of a network, or connect sites that do not have direct connections between them, due to interference or obstruction by buildings. These are intended to be the most durable and robust sites possible, but still able to be installed and maintained by Digital Stewards.

Ideally, these installations are on key institutions - such as centers of worship, community centers, municipal buildings, and clusters of small businesses - that have already been outfitted with resilient electricity sources or other backup supplies. These will have line of sight to the rooftop or interior nodes throughout the neighborhood. They can be the sites for the Internet gateways for the network or will connect to those gateways to provide Internet distribution to the rest of the network. They are also ideal sites to install servers that will provide local applications over the network. The equipment at these sites is comparable to that of the rooftop installations, but with greater signal strength and additional backup power capabilities.

These sites will consist of the following types of equipment, as shown in the detailed system diagram:

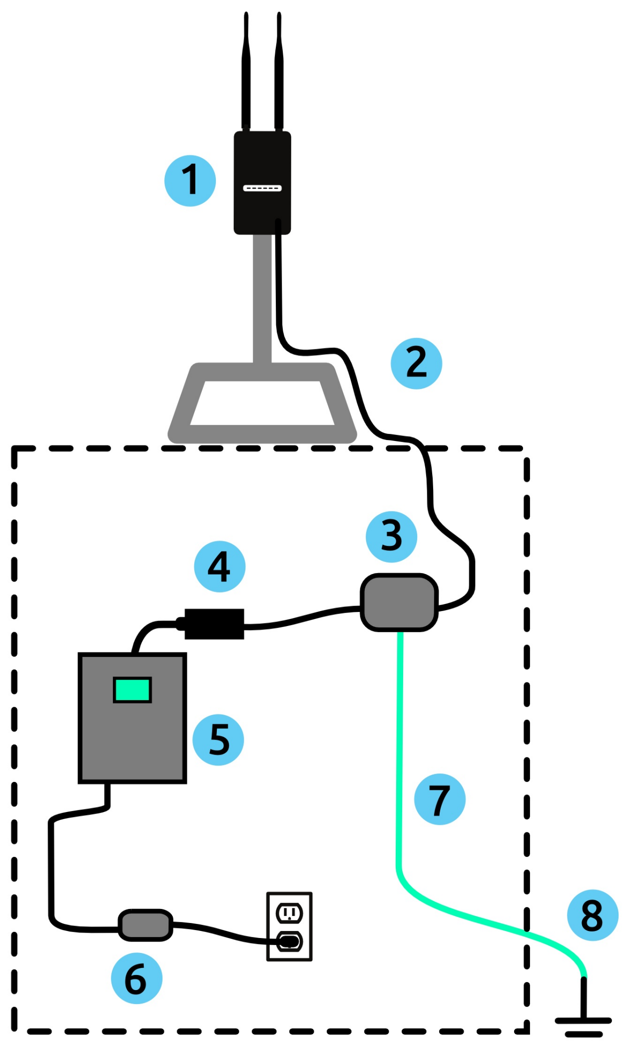
1. **High gain omnidirectional antenna - A MIMO Wi-Fi antenna with at least 10dBi of gain for extended coverage.**
2. **High powered mesh node - A powerful wireless mesh node with 24dBm of power output or greater.**
3. **Shielded outdoor grade Ethernet cable - UV resistant for outdoor use, shielding grounds outdoor mesh equipment in case of static or power surges.**
4. **DC Regulator - Maintains constant DC power level to mesh node. Provides surge arresting feature.**
5. **DC UPS unit - Keeps batteries charged from utility power, and transfers power for mesh equipment to battery when utility power fails.**
6. **Backup batteries - 36Ah capacity, wired for 24V DC output. Directly powers the mesh equipment through the DC UPS unit. Can maintain power for up to 72 hours.**
7. **AC power surge protector - An off-the-shelf surge arrestor to protect from utility power spikes.**
8. **Ground wiring - #10 copper wire grounding the vital parts of the system to dissipate static and surges.**
9. **Earth ground - The ground wiring should be bonded to a building ground, such as at the electrical panel.**



Example budgets for each type of installation are included at the end of this document.

Rooftop Installation

The majority of the network will be made up of equipment on rooftops. These are higher-power mesh nodes with some form of battery backup. When there is line-of-sight, these can mesh directly between homes, organizations, or small businesses, or use backbone mesh connections such as those attached to Anchor Institutions. In a typical network, the digital stewards will likely install and maintain a large number of these nodes, though the skill level required for each installation will vary greatly depending on the type and accessibility of the roof, power source, and neighboring mesh nodes.



Users at street level and in public places can often connect directly to these nodes, depending on the placement and proximity to the ground. Individuals, organizations, and small businesses can install their own rooftop equipment to expand the network, or install additional mesh nodes in windows to provide indoor coverage. Usually rooftop nodes will not provide interior coverage, but can be connected to indoor networks and access points to extend coverage.

These sites will consist of the following types of equipment, as shown in the detailed system diagram:

1. **High powered mesh node - A powerful wireless mesh node with 24dBm of power output or greater.**
2. **Shielded outdoor grade Ethernet cable - UV resistant for outdoor use, shielding grounds outdoor mesh equipment in case of static or power surges.**
3. **Surge arrester - Protects indoor equipment from power surges, and drains static charge from outdoor equipment.**
4. **PoE power supply - Converts electrical power to DC power for mesh nodes and injects it on to the Ethernet cable. Typically supplied with the wireless router.**
5. **UPS unit - Charges batteries from utility power and provides AC power for up to 24 hours.**
6. **AC power surge protector - An off-the-shelf surge arrestor to protect from utility power spikes.**
7. **Ground wiring - #10 copper wire**

grounding the arrestor to dissipate static and surges.

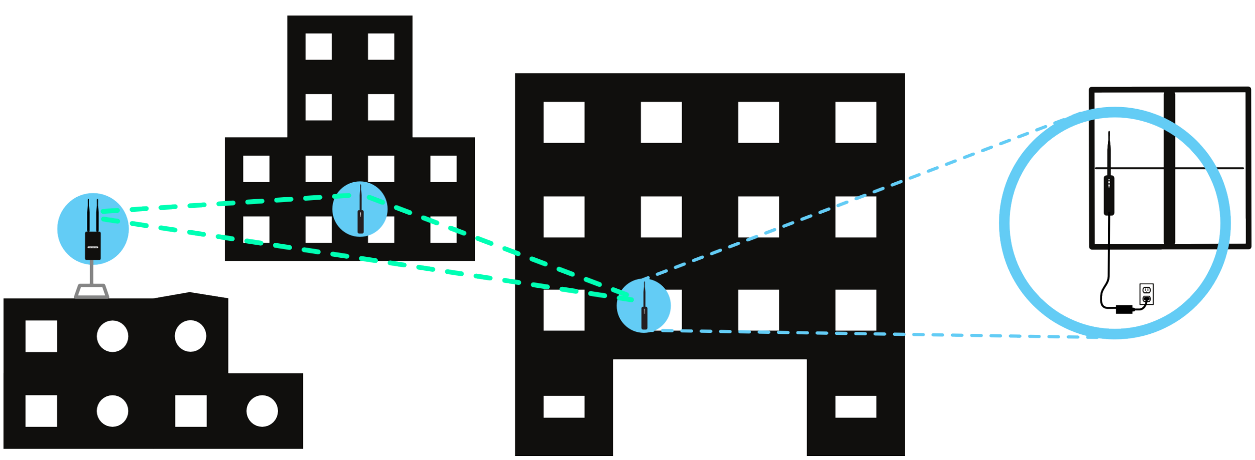
8. **Earth ground - The ground wiring should be bonded to a building ground, such as at the electrical panel.**

Interior Installations

Wireless networks have the ability to expand in an organic manner, without a large amount of planning. Digital Stewards, neighborhood residents, or other small businesses or organizations can choose to join the network by installing their own rooftop or window equipment. Especially in the case of an interior or window installation, the cost and time to install can be quite low. These mesh nodes will connect with rooftop and anchor institution nodes, and can often provide stronger street-level coverage. Users can connect directly to these nodes, often indoors in addition to on the street.

Interior installations will consist of the following types of equipment:

- **Medium-power wireless node, such as a Ubiquiti PicoStation M2 or NanoStation M2, with omnidirectional or directional antennas. The directional antenna increases the range of connections to other mesh nodes; a separate, consumer grade, non-mesh router can attach for additional indoor coverage. An omnidirectional device can serve both purposes with greater simplicity and lower performance.**
- **Ethernet cable and power-over-ethernet injector.**
- **Consumer grade uninterruptible power supply.**
- **Window-mounting bracket, which uses a suction cup to attach to the window.**



Portable Mesh Kit

Digital Stewards will maintain a number of portable mesh kits for use after a storm or disaster, when parts of the network may be down or malfunctioning. During a recovery effort, the Stewards will use these kits to re-establish the neighborhood network anywhere it has failed. The kits will contain enough basic equipment to set up new mesh nodes on short notice, even in areas where power may be down. These kits may be kept with individual small businesses or anchor institutions, and maintained at regular intervals by the Digital Stewards.

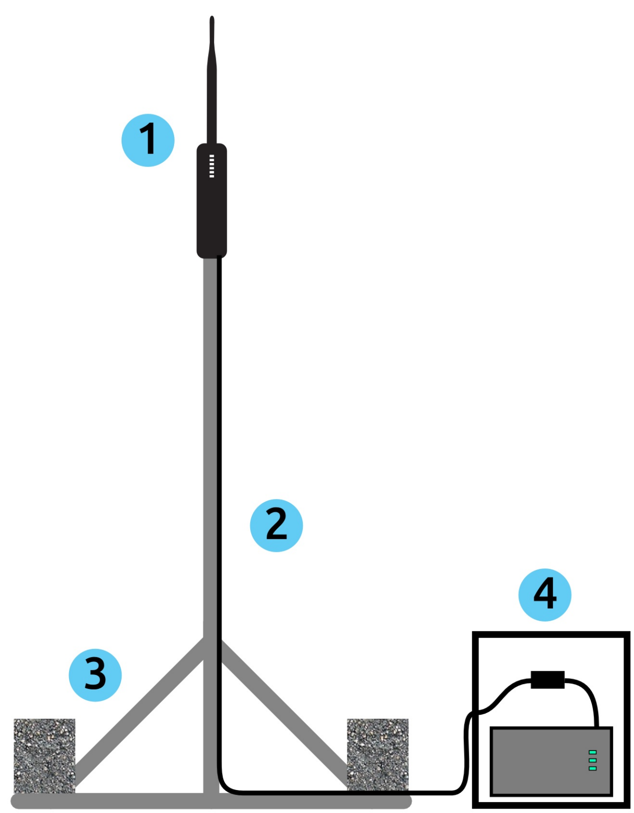
Each network will be outfitted with a number of portable mesh response kits. This kit can extend coverage to emergency aid distribution points or can replace a network node destroyed in a storm.

The kits will contain enough basic equipment to set up new mesh nodes on short notice, even where power may be down. These kits will consist of the following types of equipment, shown as a sample installation to the right:

1. **Medium-power wireless node, such as a Ubiquiti PicoStation M2, with an omnidirectional 5dBi antenna.**
2. **Shielded outdoor grade Ethernet cable.**
3. **Portable tripod mount – A sturdy, lightweight portable mast for setup on any flat surface, such as the SuperAntenna PT3 portable tripod, secured with concrete block ballast.**
4. **Portable battery pack(s), such as the Energizer XP18000A, these provides a mesh node with power for 6 to 8 hours. Shown with waterproof enclosure and DC Power-over-Ethernet (PoE) adapters.**

As an option, portable solar panels can be added to each kit to charge portable power packs and extend the runtime of the batteries. These panels may not be possible to use in all cases - some adverse weather will prevent the panels from charging the batteries, or extreme cold or rain will cause issues with the panel electronics or wiring, respectively. An example would be the Voltaic 18 Watt solar charger set, which would add approximately $200 to the cost of the portable mesh kit.

These kits may be stored with individual small businesses or at anchor locations where battery packs can be recharged from a generator or comparable electricity source.



Backup power supplies

As described above, most of the the various installations should have integrated backup power. Anchor and rooftop installation sites should have an uninterruptible power supply (UPS) that provides stability during normal operation - it prevents brief power interruptions from causing the router to turn off and back on. If electricity goes out for a longer period, OTI recommends sizing UPS units for the rooftop sites to power the routers for approximately 24 hours, and the units at the anchor sites to power routers for 72 hours before needing to be recharged or replaced.

Conclusion

The information shared in this document is intended to be a set of starting points for communities to build their own resilient networks. These are examples, and are not intended to be a construction manual - each community will require a participatory process to design their own unique solution.

We discussed three major points:

- **Social Resilience - A corps of Digital Stewards who are involved in the network construction and maintenance should lead the community through the process of building a resilient network. Technology solutions work best when the control and maintenance is understood and governed by the users.**
- **Local Communications - Broadband access to the Internet is vital, but building stronger relationships between neighbors enhances the neighborhood safety net. Local networks must have local communications features that still work when the Internet goes down.**
- **Redundancy by Design - Many small technical details are critical to keeping the network healthy before, during, and after a disaster - backup power, varied Internet connections, low-power and high-quality hardware. In this way, the physical network will hold up best in the long run.**

Keeping these basic elements in mind, we hope more communities decide to design, build, and experiment with local networks designed for resilience.

Appendix of Budgets

Anchor Institution

Item	Example	Quantity	Cost
Antenna	Ubiquiti AMO-2G13	1	$300
Mesh Node	Ubiquiti Rocket M2 Titanium	1	$230
Ethernet cable	Ubiquiti Toughcable Pro	80 feet	$25
DC Regulator	Tycon TP-DCDC-1224	1	$35
DC-UPS	Solarcraft DC-UPS 100	1	$1000
Battery Packs	Deep-cycle 36Ah 12V batteries	2	$250
UPS Enclosure	Solarcraft EP1 wired enclosure	1	$250
Mounting Kit	VMP FRM-125	1	$100
Miscellaneous	Surge protector, wiring, hardware	-	$60
		Total:	$2250

Rooftop Installation

Item	Example	Quantity	Cost
Mesh Node	Ubiquiti UniFi AP Outdoor	1	$150
Ethernet cable	Ubiquiti Toughcable Pro	80 feet	$25
Surge Arrester	Hyperlink AL-CAT6JW	1	$35
UPS Unit	APC Back-UPS Pro BR1500G w/ BR24BPG	1	$400
Mounting kit	VMP FRM-125	1	$100
Miscellaneous	Surge protector, wiring, hardware	-	$60
		Total:	$770

Interior Installations

Item	Example	Quantity	Cost
Mesh Node	Ubiquiti PicoStation M2	1	$75
Ethernet cable	Generic Ethernet cable	20 feet	$5
Mounting Kit	Ubiquiti NS-WM window mount	1	$2
Miscellaneous	Surge protector	1	$10
		Total:	$110

Portable Mesh Kit

Item	Example	Quantity	Cost
Mesh Node	Ubiquiti PicoStation M2	1	$75
Ethernet cable	Generic Ethernet cable	(2x) 25 feet	$10
Battery Pack	Energizer XP18000A	1	$180
Outdoor enclosure	Tycon ENC-PL-14x10x5	1	$75
Portable mount	SuperAntenna PT3 portable tripod	1	$330
Miscellaneous	PoE adapters, wiring, hardware	1	$10
		Total:	$675

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1. Digital Stewards: http://bit.ly/digital-stewards
2. OTI maintains an open source, Creative Commons licensed repository of the CCK graphics and modules, and we incorporate user additions, modifications and innovations into the curriculum on an ongoing basis. These materials are freely available in web and printable formats for commercial or non-commercial use by anyone who wants to build, expand or modify a resilient network in their community. https://commotionwireless.net/docs/cck/ https://github.com/opentechinstitute/project-graphics http://graphics.opentechinstitute.org/
3. Commotion Wireless: https://commotionwireless.net/
4. LibreMesh: http://libre-mesh.org/
5. Mesh Potato: http://villagetelco.org/mesh-potato/
6. Freifunk: http://freifunk.net/
7. Guifi.net: https://guifi.net/
8. OpenWRT: https://openwrt.org/
9. Serval Project: http://www.servalproject.org/
10. Ubiquiti: http://www.ubnt.com/
11. Open Link State Routing Daemon (OLSR): http://olsr.org/