Wireless mesh networking is a type of ad hoc networking solution in which the nodes participate as part of the network and act as independent routers in addition to functioning as clients. This allows for ad hoc network creation, route discovery and data transfer via WiFi over unlicensed spectrum. These nodes can be fixed or mobile. Most wireless mesh networks (WMNs) use a fixed backbone of nodes to establish a core set of intermediary routing nodes. This enables end user nodes to be more mobile without significantly affecting network throughput [9][14], however, as we will see below, the static backbone is not necessary.

Many have recognized the potential of mesh networking for rural areas where there is not much, if any, infrastructure in terms of wires, lines or multiple wireless access points. With wireless mesh networking, if one node has access to a wireless point, in theory, the other nodes in the network could also get access through that node, even though they are out of the wireless range. This allows the network to handle geographic challenges such as mountains, dispersed communities or bodies of water that typically have large amounts of attenuation or noise [10][12]. Further, WMNs are typically less inexpensive to implement given that there is no large upfront infrastructure investment needed. They tend to require lower power as well because the network is distributed across many, typically lightweight nodes [2]. Finally, mesh networks are "self-healing" in that if a node drops off, the network can rediscover routes easily and effectively. In fact, many mesh networks actually expire routes after a certain time to force route rediscovery and keep the network agile and up-to-date [12]. Due to this inherent flexibility of routes, WMNs can have high levels of redundancy and thus be very reliable.

Mesh networks may be employed in rural areas for multiple reasons such as disaster response, military, commerce or community access to education content and opportunity. WMNs for community learning can give citizens both access to the Internet, and the wider world of information and educational content, and also to each other for file sharing and collaborative learning. Further, this type of access could provide educational solutions not only to a marginalized community as a whole, but also to groups within the community that may be further marginalized or restricted in access to education, such as women or girls [11]. There are a number of examples of communities that have instituted a WMN for this type of community learning access, including Dublin [16], Taipei [17] and the Tegola Project in rural Scotland [10].

The most well known of these efforts is the One Laptop Per Child initiative.[1] A significant objective for the project was to provide students with access to other students for file sharing and collaborative learning, as well as to the wider world through the Internet. Just as previously discussed, most of the developing countries (for which the laptops were intended) did not have widespread or significant infrastructure to support Internet access. Furthermore, the intention was to distribute the laptops to individual students with the expectation that the students would carry them with them from school to home and in between, so the solution needed to support mobility of the nodes. This required a more dynamic routing solution than for static or wired networks [3]. Based on those requirements and the benefits discussed before, wireless mesh networking was chosen as the solution.

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[1] The word-limit did not allow for a further discussion of the OLPC project, so here is a brief overview. The OLPC initiative, which initially set out to have a laptop in the hands of every marginalized child in the world, has the underlying assumption that having access to a laptop will lead to better educational outcomes and more potential for progress for each student. For more, see [1].

In the OLPC mesh network, or XO Mesh, each laptop, or XO, participates both as a client and a network router. The XO was built to have the radio separate from the CPU so that the XO can continue to operate as a router even when the main processor is turned off [8]. The XO Mesh allows students to be dispersed and mobile and still access the network. And if a particular XO node can "see" a neighboring node that is connected in the mesh, the XO can join the mesh and if one node in the mesh is close to an Internet access point, the other nodes can get Internet access through that node. Again, students can get access to file sharing and collaborative learning applications, as well as potentially the wider Internet.

The XO Mesh works differently than most WMNs in that it is based on a new IEEE standard draft, 802.11s that specifies a Layer 2 WMN [13]. Most WMNs to date have been Layer 3 technologies, using protocols such as Ad Hoc On-demand Vector (AODV) to communicate via IP. But 802.11s specifies a Layer 2 WMN that employs Hybrid Mesh Network Protocol and uses MAC addresses to forward frames to the next hop [8].

Despite the advantages, there are some significant disadvantages or limitations to rural, mobile wireless mesh networking for community learning that should be considered. The first is the issue with spectrum allocation. The mesh works thru WiFi over unlicensed spectrum, but many countries have different policies around allocation and use and must be worked out by the community to avoid violations. Another significant issue is security. Mesh networks are inherently built around lack of infrastructure, which means that there will be security holes and vulnerabilities. Security attacks, such as signal jamming or MAC address spoofing, are not typically protected against [3]. A similar, but equally critical issue is confidentiality and privacy. There is no authentication of the neighboring nodes when a XO joins the mesh or passes data. Also, data is passed in plain text and is thus is vulnerable to sniffing [3]. Scalability is also another issue with WMNs in general, typically because they use a single radio signal for all communication and data transfer. While there are new specifications for double or multiple radio mesh networks, many of the existing implementations, including the XO Mesh, use a single radio, which limits scalability. Just as the Mongolians have recently experienced, "*Once a certain density of students is exceeded, a wired backbone and conventional access points will be required*" [6]. Finally, WMNs are an evolving solution. 802.11s is still being drafted and changes are difficult to roll out to these rural villages which already have a mesh established.

Suggestion

Based on the analysis above, it is clear that wireless mesh networking is a feasible solution for communities to easily, efficiently and inexpensively deliver broadband access to their citizens and schools for access to educational content and collaborative learning. With the proliferation of cell phones, exploration of smart phone nodes would further lower the barrier to entry and support rural citizens in their daily lives.

That said, for there are clearly issues with WMNs to work out such as security, privacy and scalability. Some western efforts, such as the OLPC initiative, which try to develop a solution separately and deliver it upon rural communities, often come with assumptions that because the communities are marginalized and underdeveloped, privacy and security are not an issue. Or they plan and execute the initial development and delivery of the supporting technology, but do not plan for continued maintenance or growth. So before investing in such an initiative, I would highly recommend that the issues be worked through first. At this point, the most beneficial investment would be to those evolving the standard and technologies, and of course, donations to the rural communities themselves to implement their own networks.

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Appendix

Several of the underlying functionalities of the XO Mesh were particularly interesting to me in light of what we have learned so far in i250, so I wanted to briefly discuss each – outside of the paper itself since I was already above and beyond the initial word limit. I also felt these specifications were not necessarily important to investors – they really need to know the benefits and limitations.

How an XO Joins the Network: *(adapted from [3])*

When an XO is initially activated or powered back up, it broadcasts a Dynamic Host Configuration Protocol (DHCP) request and Route Request (RREQ) to a Mesh Portal anycast address on all three wireless channels (1, 6, 11), which have currently been proposed for XO Meshes. It then listens on all three channels for a Route Reply (RREP) from the Portal. If multiple channels are available, the XO will choose the one that has the least number of hops as long as the signal strength is not significantly lower. If more than one channel is available with an equal number of hops and bandwidth, the XO will select one randomly. At this point, the XO is connected to the mesh and can begin receiving and forwarding frames. [3]

How Routes are Discovered: *(adapted from [3])*

WMNs need to be flexible and agile and able to handle mobile and changing routes. The XO Mesh handles this in the following way. If an XO in the mesh network has data to send or forward to unknown destination, it again broadcasts a RREQ, this time with the MAC address of the destination node as the end target. Neighboring nodes propagate the request and as each node forwards the frame, it stores the route in its routing table as the *reverse route*. Once the destination receives the request, it responds with a Route Reply (RREP), which gets propagated back through the network to the sender XO. Again, the intermediary nodes store the route in their routing table, this time as the *forward route*. Then for future communication between the sender XO and the destination, the forward route is used for data frames and the reverse route for control frames. This discovery process allows the network to be agile and react to nodes that have dropped off the network. If a frame is unable to be transmitted after the maximum number of times, the route is marked as invalid and the sender XO will start the route discovery process over and of all the intermediary nodes will update their routing tables appropriately. [3]