Wi-Fi Community Area Networks Enable A Connected Community

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Abstract - We propose a *Community Area Network (CAN)*, which is an all-wireless network connecting a community or a metropolitan area. This is a multi-hop network consisting of many Wi-Fi supernodes, each of them serving a number of resident homes and/or mobile users. Users in the covered area are able to communicate with each other through the Wi-Fi network while connecting to the Internet. This provides an independent community network that connects every household to local government and organizations.
Keyword - community network, wi-fi, wireless network, distributed system.

I. Introduction

Despite the incredible growth of the Internet since the early 1990s, many citizens still do not have easy access to the Internet. Only 13% of families have broadband connections to Internet and another 44% have dialup access [1]. Access to the Internet is an issue that affects people at home, at school and in the community at large. This situation becomes worse in the low-income or minority communities. Neighborhoods with less access to technology are at a disadvantage in contrast to those neighborhoods with more access when they come to seeking better education, better jobs, even higher levels of civic participation. Now, more than ever, unequal adoption of technology excludes many from reaping the fruits of the economy.

Telco and ISP control the network resources so the community has nothing to do with it. This situation has begun to change in the past three years. The IEEE 802.11 Wi-Fi provides a low-cost solution. IEEE 802.11a and 802.11g are able to provide up to 54Mbps wireless bandwidth up to 100 meters. Enhanced by an antenna, it can transmit signals up to eight kilometers [2]. The cost of Wi-Fi equipment has drastically declined. The bandwidth is free. This provides an opportunity to build a zero-cost community network. In fact, hundreds of grass-root Wi-Fi networks are operating around the world.

We propose a *Community Area Network (CAN)*, which is an all-wireless network connecting a community or a metropolitan area. This is a multi-hop overlay network consisting of many Wi-Fi supernodes, each of them serving a number of resident homes and/or mobile users. Users in the covered area are able to communicate with each other through the Wi-Fi network, in addition to the connection to the Internet. It provides an independent community network that connects every household to local government and organizations. This Wi-Fi network provides a substrate structure on top of which we can build a Wi-Fi overlay using the power and storage of the supernodes. The Wi-Fi overlay provides variant network services, such as geocast, multicast, caching and mirroring. On top of the Wi-Fi overlay, we build a service platform. The functions of the service platform include, but are not limited to, information broadcasting, information gathering, peer-to-peer local search, lookup and tracking, pervasive structure support, video conference, and video-on-demand services.

The Wi-Fi community area network has many advantages. Similar to the grass-root Wi-Fi, it provides a low-cost access to the Internet. Individuals are creating the community area networks — of the people, by the people, and for the people. CAN will help bridge the digital divide by providing low-cost or free access to digital information. For non-profit applications, it provides the facility for government information and document service, law enforcement, information sharing, and town meetings. It also can be used for community security or elderly care. For commercial applications, as an example, the video distribution platform may allow commercial partners to provide the Video-on-Demand (VoD) service. It is important to note that most of the above functionalities do not depend on the Internet connection.

A major advantage of CAN is that the community owns the network. Also, CAN is able to optimize traffic and make efficiently use of network resources. Currently, end-users are connected by different providers. Assume that a cable modem user connected to Comcast sends a video file to a neighbor with DSL. The packets could be routed from Albuquerque to Denver and sent back to the neighbor. It is the same if you use the Internet for a town video conference. This is due to the vertical connections in the Internet structure. With CAN, the horizontal interconnection allows the packets to be transmitted directly between the wireless links. The latency and quality of the real-time video transmission will be improved. The burden of the global Internet will be reduced also.

II. Background

Approved in 1997 by the IEEE 802 committee, 802.11 details the framework necessary for a standard method of wireless networked communications. The dedicated hardware, so called the Access Point (AP), provides a basic or extended service set that builds the wireless infrastructure. The usefulness of Wi-Fi significantly depends on its coverage range. The maximum distance of the original Wi-Fi is only 100 meters so it can only be used in buildings or houses. However, enhanced by an antenna, the distance can be significantly extended. An omnidirectional antenna is able to cover an area of five square kilometers. A phased array antenna is able to transmit signals to four kilometers in a 100° field of view and four of them is able to cover an area of 50 square kilometers [3]. With a Pringles can antenna [2], it can transmit signals up to eight kilometers, or even 40 kilometers with a parabolic dish. This coverage range makes a wireless community area network become practically feasible.

CAN is motivated by the grass-root Wi-Fi. In the past three years, the grass-root Wi-Fi has increased in popularity all over the world since 802.11b became a popular wireless networking technology and is supported by a number of hardware manufacturers. More than a hundred independent local groups have been formed with different plans to deploy their own community networks, from a simple “hot spot,” that is, a single AP, to a group of APs connected by fibers. They hope that someday the Wi-Fi network will be owned and shared by the community at large.

III. Community Area Network (CAN)

The major issue to be addressed in the grass-root Wi-Fi is that the connection between APs depends on the commercial

Internet. In fact, most grass-root Wi-Fi groups intend to provide users with Internet connections, not the connection between users.

Like many ideas whose time has come, the wireless community network is unfolding now. Take a look at the lily pond and frogs analogy described by Dr. Negroponte at MIT Media Lab in [4]: "... further down the street, beyond the reach of my system, another neighbor has put in Wi-Fi. And another, and another. Think of a pond with one water lily, then two, then four, then many overlapping, with their stems reaching into the Internet. ... In the future, each Wi-Fi system will also act like a small router, relaying to its nearest neighbors. Messages can hop peer-to-peer, leaping from lily to lily like frogs – the stems are not required." The concept of this open community network is presented as a vision for general-purpose ad-hoc networks. CAN is an all-wireless open network to connect the community and government. That is, wireless communication is being used between end-users as well as between end-users and the global Internet.

The main advantage of all-wireless network is its flexibility. We use a point-to-point, topology-aware routing protocol to build CAN. Different from a grass-root Wi-Fi that routes messages through the general Internet, communication between two users in CANs will be routed directly. This approach uses the network more efficiently with less delay.

Besides its advantage of flexibility, an all-wireless network has some problems, however. Consider the lily pond and frogs analogy: as more and more lilies grow in the pond, each has a smaller circle. The power must be reduced to avoid interference between each other. Thus, the number of hops to transmit a message increases. A long-distance routing of a message through many unreliable links may have a large latency and packet loss. Routing through many hops also consumes network resources. To implement a reliable and efficient routing, we propose a community area network infrastructure with *supernodes (SN)*. An SN is defined as a stationary and relatively reliable node, with an antenna for long-distance signal transmission, powerful enough as a router, and some storage space for advanced services. In contrast, a *normal node (NN)* can be a small device without a big antenna, storage space, or good power. Also, an NN needs not be reliable, it can be on and off at any time. The SN is a key element in CAN. It serves as a portal to households and mobile users who send and receive messages. It also works as a message repository point as well as a message forwarding node. Separate communication channels are allocated for SN connections. The SNs can be arranged roughly as a cellular structure, as shown in Figure 1. In this arrangement, an SN

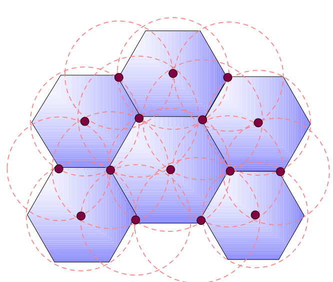

Fig. 1. The Community Area Network Structure.

is able to reach at least six adjacent SNs so the network has good connectivity. This structure exhibits rich connectivity and locality. An NN with an interface card can connect to one of the SNs in addition to the peer-to-peer connection of other NNs. Some locations might be covered by different SNs. In case some SN fails or does not have a good connection due to weather conditions, an NN will be able to connect to other SNs. The distance between SNs can be adjusted according to the service area. In an area where the number of users has grown to the point that the system is overloaded, the power of the SNs is reduced, and the overloaded cells are split into smaller microcells to permit more frequency reuse. The structure of an SN is shown in Figure 2. A common PC can be used as the router, connecting to a number of APs. Each AP has an antenna attached. One of them is with an omnidirectional antenna which is used to connect NNs. The phased array antenna can be used to extend the coverage area. Other APs have directional antennas, such as Sector or Parabolic antennas, which connect other SNs. The optimal number of APs is to be determined together with the channel assignment algorithm.

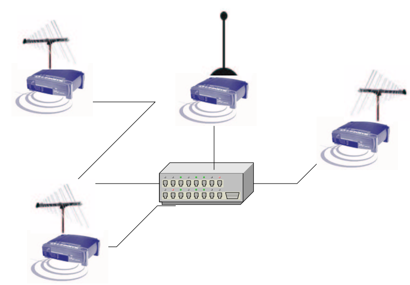

Fig. 2. The SN Structure.

The CAN communication architecture is shown in Figure 3. The all-wireless communication is supported by a network stack including a transport-layer location addressed protocol, a geographic forwarding with adaptive scheduling, and a prioritized MAC. This network stack embodies a set of efficient and localized algorithms to reduce the end-to-end delay and minimize the network congestion. Two sets of communication channels are used to separate the SN-to-SN communication and SN-to-NN communication. The SN-to-NN communication is similar to the cellular mobile phone system where seven channels can be used for cell separation. More channels are necessary to separate the SN-to-SN communication. 802.11a and 802.11g could be used together to obtain more channels. At least 30 channels are required for a static separation. However, there are only three non-interference channels in 802.11g and 13 (or 24 in planing) non-interference channels in 802.11a. Thus, dynamic channel assignment becomes necessary which may reduce the number of channels required. However, the co-channel interference may still occur. The MACA MAC-layer protocol [5] can be used for collision avoidance. With the RTS/CTS dialogue, the hidden terminal and exposed terminal problems can be resolved.

A crucial issue of CAN is its scalability. It depends heavily on the routing algorithms. The Wi-Fi CAN is a mesh structure and its connectivity is determined by the access range of nodes. Two scalability issues are to be addressed. First, the size of the routing table must be under control. Second, the network traffic must be balanced. When the network becomes

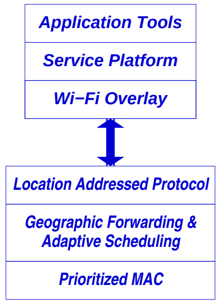

Fig. 3. The Community Area Network Communication Architecture.

larger, the network traffic, especially in the center of the network, becomes heavier. Efficient routing algorithms are required to minimize the maximum link stretch. To make the load more balanced, some traffic may route to a lightly-loaded portion of the network instead of the shortest path. For the regular hexagonal structure, fixed routing can be used. However, the network structure is not always regular. Different ad-hoc routing protocols, pro-active and reactive, can be used for SN routing [6]. DSR and AODV are two commonly used routing algorithms, however, they are scalable to only about one hundred nodes mainly because they require global routing information. Connectionless routing could be applied but is not efficient for this fixed wireless architecture. The zone routing protocol (ZRP) [7] could be used for this purpose. These algorithms are location-aware which takes advantage of geographical information to efficiently route messages between the SNs.

In CAN, location addresses are used to identify nodes. This location address facilitates the geographic routing. Here, each node in CAN may have three addresses, the IP address, the MAC address, and the location address. A Modified Address Resolution Protocol (MARP) is used to translate between them.

Last, we briefly discuss the end-system for users. The end system can be any device such as computers, TVs, cellular phones, or PDAs with a wireless interface card. A popular setting in a household could be a wireless card with a small indoor antenna, an Ethernet Set Top Box (STB), and a TV. The cost of the wireless card and the Ethernet STB may cost only about $150, compared to $450 for a digital cable STB.

IV. Wi-Fi Overlays

The CAN infrastructure provides basic service as end-to-end connection in the wireless network, but more service styles are needed for advanced applications. These service functions can be implemented in the overlay network level, which is built on top of the Wi-Fi substrate network. Different from the Internet where proxies are deployed for an overlay, in CAN, the supernode itself can be used to build the overlay. An SN can be used as a replication engine for geocast and multicast. Its storage space can be used for caching or mirroring. Thus, these service overlay functions can be easily implemented.

Geocast and multicast

Geocast and multicast are important functions for information dissemination. A routing algorithm connects nodes to build a multicast tree. The requirements of low latency and low bandwidth consumption usually contradict. An algorithm has been developed to optimize both requirements and to build a multicast tree with a low complexity [8].

Caching

Caching plays an important role in the Internet. It can be used in CAN to reduce traffic, minimize message latency and increase network efficiency. Part of the storage space in each supernode may be used as caching space. Cooperative caches [9] also could be used with multiple supernodes.

Mirroring

Important and frequently accessed contents can be replicated to many mirroring sites. The Content Delivery Network (CND), deployed in the Internet [10], effectively reduces the network traffic. Due to limited wireless bandwidth, mirroring is more important in CAN. We can utilize the storage space in each supernode as a mirroring site. Contents, especially those rich contents, can be replicated to significantly reduce the network traffic.

V. Service Platform

The use of the community area network is only limited by imagination. Possible services that can be provided include information broadcasting, information gathering, peer-to-peer local search, lookup and tracking, and video conference. The service platform is described in this section, and in the next section, we will present some sample applications.

Information broadcasting

Information broadcasting is an important function in a CAN. It allows government, schools, and community organizations to make important or emergency announcements. Some facilities provided by the web, such as a bulletin board, can be used for this purpose. In addition, emergency announcements also can be inserted into the TV screen or alarm system. A priority system specifies different types of information. A QoS mechanism guarantees dissemination of emergency information.

Information gathering

An information-gathering system can be used for gathering public opinions, comments, instant polls, or votes. Information can be gathered from sensor networks or pervasive devices, too. From the system point of view, an aggregation system needs to be implemented. Instead of transmitting information individually, a dynamic aggregation tree can collect information more efficiently. In addition, mechanisms such as policy-enforcement, time stamp, privacy, identification, authentication, anonymity, and statistics tool are to be integrated into the system for applications such as online voting or polling.

Video conference facility

The video conference is an essential service to enable interactions within the community, interest groups, and school districts. It is also useful for interaction between government and citizens. Multicast function and large bandwidth are two essential requirements for the video conference facility. The 802.11a or 802.11g is able to provide enough bandwidth for this purpose. The video conference can be implemented as all-to-all multicast or shared-tree-based.

Lookup and tracking

The lookup and tracking function is similar to the search function, but instead of searching for information, it searches real objects. Therefore, it has some different requirements. Wireless sensors can be used to detect objects. The real-time requirement could be enforced. This function can be used for child and elderly care, for monitoring some special event, or for security systems. Privacy, security, and authentication are important issues to be addressed for the lookup and tracking service.

VI. Application Tools

CAN enables many interesting applications including government-information and documentation service, regulation and law enforcement, information collection and information sharing, culture exchange, community and interest group meeting, community security, society education, digital democracy (online campaigning and voting), elderly care, video service, and all sorts of other innovative, but unforeseen, applications. Tools are to be developed for these applications utilizing the facility functions supplied by the service platform. Here, we only describe three applications: online education, elderly care, and video service.

A) Education. Wi-Fi community area networks provide affordable connections to every household in rural and urban communities. It is an ideal tool for providing online education. Currently, many institutes provide free online courses at different levels. However, not every household is able to utilize these courses since no network connection is available. CAN can solve this problem by reaching every household in the community.

Probably a more important application is to provide local education programs within a CAN. Local school districts may utilize CAN to offer K-12 education. This is especially crucial for home schools. People who do not pursue a degree may learn various skills from the online courses, too. The online courses can be made suitable for different community groups and are replicated at the mirroring sites close to them. For example, courses designed for the Indian country can be put near the Indian reservations.

B) Elderly Care. Pervasive computing has been used in nursing homes for elderly care. Pervasive devices such as badges and sensors assist residents to continue living as normally as they can [11]. Whenever possible, many seniors choose to live in their own home instead of a nursing home. To assist them achieve this goal, pervasive devices installed in a home need to be connected to necessary people who can take care of the seniors whenever necessary. CAN is suitable for this purpose. An intergration of pervasive computing and CAN will assist these people to have as much autonomy and responsibility for themselves and their environment as possible.

A physical setting of the pervasive environment may include a locator wristwatch and sensors placed everywhere for the purpose of tracking. When people become disoriented and begin to wander, an alarm alerts staff to come help. Emergency buttons allow people to seek help. Pervasive sensors, such as wristwatch monitors and under-bed weight sensors, track vital signs and health indicators.

C) VoD Service. One application that utilizes the high bandwidth of CAN is the Video-on-Demand (VoD) service, which is a value-added service. It can be operated by a commercial partner who leases the video service platform provided by CAN. In this way, CAN can generate income for the maintenance of the Wi-Fi network and therefore provide free service for basic network connections.

The video service requires large network bandwidth. Although the 802.11a or 802.11g may provide up to 25 Mbps of useful bandwidth, this bandwidth only can support about 80 300Kbps MPEG-4 streams. Therefore, innovative techniques must be adopted to make a wireless VoD service possible. Here, we describe a solution that is modified from our "edge station" approach [12]. This method utilizes the storage space in supernodes to effectively reduce the bandwidth requirement of VoD service. Each supernode is equipped with low-cost, large-capacity storage devices such as two or three 100GB IDE disks. These disks are able to store many videos but are not expensive since each 100GB disk now costs less than $100. A supernode is able to mirror hundreds of two-hour MPEG-4 videos. Most requests can be satisfied locally. Those requests that cannot be satisfied locally will be forwarded to the central server, which delivers video streams to the clients through CAN. Only a small percentage of requests will be forwarded to the central server so a small amount of network bandwidth is required for routing the video streams. Each supernode may support hundreds of residential homes. The central server is able to control the contents stored in the supernodes and to update the contents by geocast, using a relatively small amount of network bandwidth.

VII. Concluding Remarks

CAN, as a mission-oriented, dynamic community network, will make our community and government connected. The way community and government interact will be revolutionized. It is able to deliver services to all sectors of the community, no matter their location, income level, or expertise with computers. This will make an independent wireless community network. Due to its rich connectivity, it can function as a secondary network in case of disaster.

The community network is emerging as an alternative to the existing Telco network. It has advantages of low cost and easy deployment, especially for the residential access network. However, it is not for long-distance communication. Its impact on the current Telco is not known yet. In the future, will Telcos provide only long-distance service and community area networks provide residential access networks and local connections? Or both Telcos and community networks will run in parallel? The impact of community-owned networks on Telco needs to be studied in future research.

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