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Research Article

A Wireless Grid in Ubiquitous Broadband Wireless Services for Mega-Event Scenario and its Distributed Power Control

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Abstract: Wireless grid can provide consumers ubiquitous broadband wireless services with convenience, robustness and mobility, which is one of the most promising alternatives of fixed wireless access networks. As the deployment of Wide City has accelerated quickly, this study focuses on the key technologies of wireless grid in ubiquitous broadband wireless services, such as antennas, MAC design, channel assignment and interface scheduling. A novel hierarchical wireless network based on WiMax-WiFi grid is proposed for mega-event. As a key enabling technology for wireless grid, a distributed power control algorithm for WiFi AP is proposed in this study to achieve the load balancing and the improvement of network performance.

Keywords: Load balancing, mesh, power control, WiMax, wireless grid, WLAN

INTRODUCTION

Wireless grid, also called wireless mesh, is an emerging architecture for the next-generation computer networks. Among many possible approaches, wireless grid, which provides consumers ubiquitous broadband wireless services with convenience, robustness and mobility, is one of the most promising alternatives of fixed wireless access networks (Ohmori *et al*., 2007; Berezdivin *et al*., 2008).

Mega-event refers to the global or regional festival of culture and technology, such as EXPO Communication, which in general occupies several pavilions and will have large numbers of visitors. In order to provide convenient information and communication services to mega-event, wireless grid is a competitive choice. Although a wireless grid can be built with the current technology, it is neither efficient nor scalable and some critical problems should be solved before large-scale deployment, such as hidden terminal, interferences between nodes and weak collision-immunity MAC protocol. This study focuses on the key technologies of wireless grid in ubiquitous broadband wireless services for mega-event and proposes a novel wireless heterogeneous networking example based on WiMax-WiFi grid.

Currently, Gen1 wireless access network based on Wireless Fidelity, or as referenced in this study as WiFi/802.11, is available in most places due to the low price of WiFi devices. Many major cities are deploying wireless broadband service using the WiFi technology. Wireless access is becoming a public infrastructure just like the transportation system in a city. Recently, the rate of deployment of citywide wireless broadband networks (Wide City) has accelerated quickly. Philadelphia has planned to deploy a wireless broadband network that covers the entire city. New York City has planned to build a public safety wireless network of unprecedented scale and scope with a capacity to provide tens of thousands of mobile users. Besides metropolitan areas, rural area also plans to build wireless broadband networks (Akyildiz *et al*., 2004; Campbell *et al*., 2000; Gang *et al*., 2008).

On the other hand, wireless grid, which is considered to be the second-generation of wireless access network, is an emerging technology that showed substantial signs of growth, in particular, in 2010 and 2011. The prospects for continued growth are also substantial for future. Wireless grid will bring many new features and applications, such as hot zones, to both business and consumers. Currently, many researchers and companies use wireless grid technology to construct a wireless wideband communication network, not merely a wireless access network. Wireless communication can be established between WiFi hotspots similar to that between a terminal client and a territorial net.

ARCHITECTURES

Currently, the most popular broadband wireless network architecture is WiFi hot spots stemmed on wired access networks. Many providers work on the WiMax access network, which can be connected to WiFi hot spots to form an all-wireless network, though the connections among WiMax Base Stations are still

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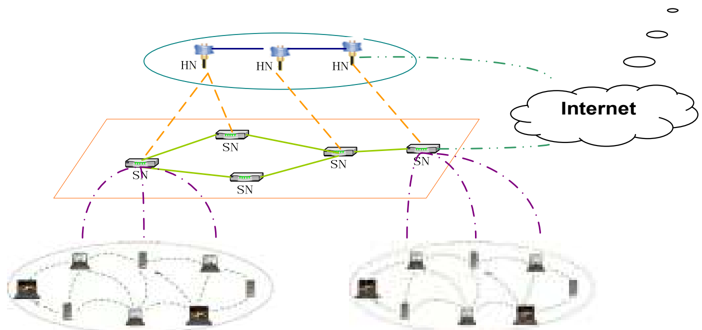

Fig. 1: An all-WiFi grid

wired. There is much possible architecture for all-wireless broadband networks; among them ALL-WiFi and WiMax-WiFi grids are two promising alternatives.

This study firstly proposes an ALL-WiFi grid with a three-level structure. In this structure, there are three types of nodes. The Normal Node (NN) is an end-system, which can be mobile. It could be unreliable and can be on-line or off-line at time. It could have no big antenna, nor big computation power. The Super Node (SN) is a reliable node and placed in a relatively fixed location. It has powerful antennas for a longer distance range, sufficient power for forwarding data and large storage space to provide advanced services. Similar to the wireless routers in commercial mesh networks, SNs forms a wireless grid to provide a wireless backbone. However, different from most of the current mesh networks, an SN with multiple programmable radios is able to deal with multiple simultaneous transmissions in different spectrums. This MCMI structure will be described in sub section (Exhibit management and searching). SNs provide access to fixed or mobile users while connecting themselves into a wireless grid. It also provides storage space while forwarding data. SNs provide an ad hoc wireless grid connection, but the ad hoc network usually is not scalable as a message transmission of a long distance will has many hops, reducing its reliability, increasing the delay and consuming network resources. The situation becomes worse in a dense area where there are many NNs to be served and the power of each SN must be reduced to avoid interference. The Hyper Node (HN) is a powerful node that provides long-distance communication to tens of kilometers. The communication between HNs is point-to-point communication with powerful antennas. HNs provide long-distance data forwarding to minimize the total number of hops, increase the scalability of the wireless grid. As an important type of nodes in the ALL-WiFi grid, HNs make the grid highly reliable and reduce the network latency. With HNs, an ALL-WiFi grid may scale to a metropolitan area.

This heterogeneous structure is illustrated in Fig. 1. It can be described as a cellular structure. An SN may connect too many neighbor SNs, so the grid has good connectivity. An NN is able to talk to other peer NN while connected to an SN. In fact, an NN can be covered by different SNs, so it may connect to another SN when some SN is busy or fails. The distance between SNs can be computed by the service area. When an SN is overloaded by too many NNs, its power will be reduced and more SNs are deployed to obtain higher frequency reuse. The HNs are sparsely deployed spread over a large area to provide long-distance communication.

An NN is a normal end-system with common interface card and a small antenna. An SN may have a number of interfaces with multiple antennas. Omni-directional coverage is required to connect to NNs. MIMO antennas can be used for this purpose due to their long communication range. It also can be an omni-directional antenna or a sectored antenna composed of a few directional antennas. Separate antennas may be required to connect to other SNs and HNs. An HN is equipped with high-gain directional antennas to connect each other, as well as to connect to SNs.

In the All-WiFi grid architecture described above, the long-range top-level communication is performed by HNs. Although a WiFi access point with high-gain antennas is able to transmit data to tens of kilometers, its capacity is limited by unlicensed spectrum, limited power and interference. Another consideration is the cost of towers for HNs. An alternative is to use WiMax to form the top-level structure, where a number of Subscription Stations (SS) connect to a Base Station (BS) with wireless communication while wired communication is used to connect BSs. It is also possible to use wireless communications for the connections among BSs. An interface between the SS in WiMax and SN in WiFi is necessary to use WiMax as the top-level of the grid. The structure of WiMax-WiFi grid is shown in Fig. 2. The advantage of this structure over the All-WiFi is that the WiMax provides a reliable long-distance connection.

Compared WiMax-WiFi to WiMax, its connectivity is enhanced. Also, the WiFi grid is able to balance the load among different BSs. Furthermore, local traffic among SNs and NNs can be directly exchanged in the WiFi grid without loading the WiMax network. The research issues of WiMax-WiFi grid include minimization of total deployment cost, load balancing among BSs, etc.

In addition to the wireless grid, the sensor network is an integrated part of Wireless City. Sensor networks can be used for real-time information collection,

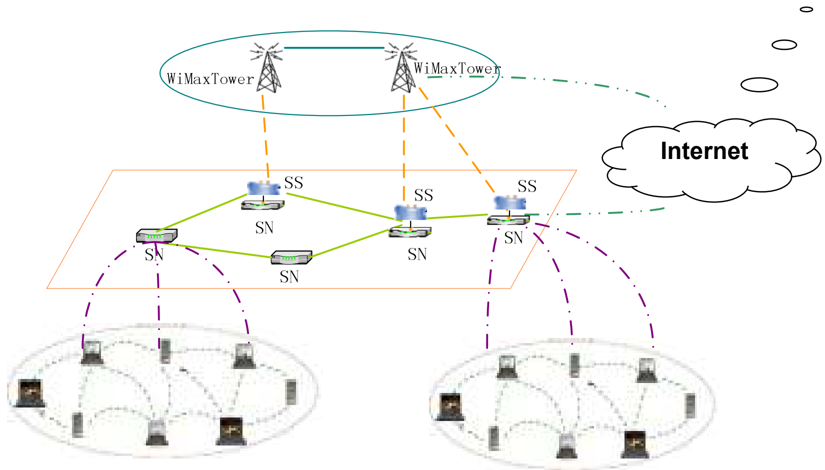

Fig. 2: A WiMax-WiFi Grid

monitoring and surveillance, tracking and pervasive applications. With wireless grid, the performance of sensor networks can be significantly improved as many access points to the wireless grid reduce the delay and network traffic in the sensor network. A gateway between WiFi and 802.15.4 will enable the seamless connection of the wireless grid and the sensor networks.

KEY METHODS

Although a wireless grid can be built with the current technology, it is not efficient, nor scalable. The following issues must be studied before the next generation of wireless networks or grids can be established.

- **Antennas:** The advanced antenna technology triggers the revolution of the second-generation wireless networks. Currently, MIMO technology, Software-Defined Radio (SDR), directional antennas, phased arrays and adaptive arrays define energy-efficient and spectrum-efficient wireless. The antenna for SNs plays a significant roll in our proposed wireless grids. Three types of connections that are SN-NN, SN-SN and SN-HN connections, each of them requires different antennas. The SN-NN connection must cover an area, as there can be many NNs and they can be mobile. MIMO is suitable for this connection, which may provide communication range of 200 to 300 m. However, in many cases, this communication range is not long enough for the last-mile connection. Phased array is a candidate for this connection. It also can be used for mobile NNs while providing a communication range of up to 1 kilometer or longer. However, phased array is still expensive at this time. Yet another solution is to use the sectored antenna. The sectored antenna consists of K directional antennas; each of them covers 2 π/K degrees of angles. The NNs in the service area of an antenna will connect to it. Another advantage of sectored antennas is that at most K simultaneous connections can be established at the same time. New MAC and channel/interface assignment algorithms need to be designed as will be discussed later.

A number of options exist for the SN-SN connection. In a cellular arrangement, the communication range between two neighbor SNs is normally longer than their coverage range. This connection can share the antenna with the SN-NN connection as they require similar communication range. The SN-SN communication range is normally longer than the SN-NN communication range since SNs may have higher power and better antennas. Separate directional antennas, each of them points to an SN, can be used to provide longer communication range. Phased array may be used for the SN-SN connection. However, though phased array may provide a longer communication range, it is expensive and the current directional MACs do not fully utilize its potential. The maximum communication range will be achieved when both the transmitting antenna and the receiving antenna are in the directional mode. It is difficult to align two beams of the phased array. An open problem is to design new MAC for an efficient usage of phased array antennas. In addition, complexity and cost are still the major concern of using directional antennas though some low-cost directional antennas are available.

The SN-HN connection normally requires a longer distance than SN-SN connection. Although it may share the antennas with SN-SN connection, a separate high-gain directional antenna could be necessary. This antenna could also be used for the HN-HN point-to-point connections.

- **MAC design for MCMI:** Software-defined radio enables a wide range of possibilities to fully utilize

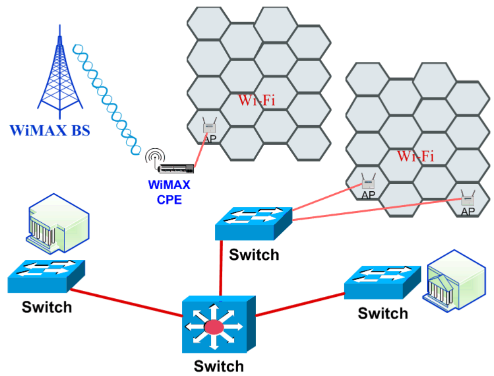

Fig. 3: Hierarchical wireless network based on WiMax-WiFi mesh configuration

the spectrum. Dynamic spectrum management is to be developed that exploits the capacities of programmable wireless systems (Akyildiz *et al*., 2004). Previous wireless MAC targets on conflict avoidance, however, existing MAC does not work well for ad hoc networks. The RTS/CTS protocol does not prevent conflict in some situations and over-prevents conflict in other situations. Therefore, it is a trade-off of loss and space reuse. Some sophisticated MACs have been studied. New protocols include Multi-channel MAC (MMAC), Directional-antenna MAC (DMAC), etc. However, MAC for the next generation wireless networks using Multi-Channel-Multi-Interface (MCMI) and directional antennas has not been fully studied. Although there is some multi-channel single-interface MACs, how to design an MAC for MCMI node is an open problem. The use of directional antennas can drastically reduce interference and the chance of conflict becomes small. MACs for different directional antennas need to be studied (Campbell *et al*., 2000).

- **Channel assignment and interface scheduling for MCMI:** When many channels are available, multiple transmissions can exist in the same area. With multiple network interfaces in a node, the node is able to send/receive many messages at the same time. However, only with a proper Channel Assignment and Interface Scheduling (CAIS) algorithm the potential of MCMI can be fully exploited.

Two major approaches for channel assignment are static and dynamic assignment algorithms. Static channel assignment assigns a channel to a pair of nodes so that it will not interfere with the neighbor nodes. Though this approach is simple, more channels are required. On the other hand, dynamic channel assignment assigns channels at runtime. It is more complex but needs less number of channels.

Without programmable radio, a single interface will be able to use only a single channel, but more than one interface can utilize multiple channels. This is called the multi-radio scheme. Algorithms designed for multi-radio are basically not applicable to programmable radio. There are many fundamental problems are to be solved for MCMI channel assignment. Some of them are listed as follows:

- How many channels are needed for a given wireless setting?
- What is the upper bond of number of channels given a density of nodes?
- How many interfaces are needed for a given wireless setting?

Due to the complexity of the channel assignment problem, suboptimal solutions could be used to simplify the design. Two of them could be the Fixed Sending Channel (FSC) and Fixed Receiving Channel (FRC). In FSC, a node sends message using a predefined channel so that any node that want to receive messages from the node tunes to the channel. In FRC, a node fixes its receiving channel so that any node sending messages to the node uses the channel. The advantage of FSC is that the channels can be pre-assigned to avoid the interference; however, a protocol is necessary to tune the receiving channel at the receiving node. On the other hand, in FRC, a node want to send a message to a destination node only need to tune to the receiving channel, but potential conflict must be resolved. In any case, FSC and FRC are easier to implement than free channel selection. A comparison of these approaches is to be conducted.

- **Communication range, capacity, scalability and robustness:** The most critical metric of wireless grids is the communication range. Without sufficient communication range a large-scale wireless grid is impossible. Currently, common WiFi access point can transmit to about 20 m to 70 m, depending on the surrounding environment. With the MIMO technology, it is expected that the communication range will be extended to 200 m to 300 m. This communication range is still not sufficient for SNs. Thus directional antennas are necessary for SNs. For any wireless grid, the reliable communication range must be carefully evaluated.

The second metric is the capacity of wireless grids. Currently, the bandwidth of 802.11 g with MIMO can be as high as 100 Mbps. It is still not sufficient for a large-scale wireless grid. The bandwidth must be managed properly. All the protocols for MAC, routing and channel assignment affect the system capacity. Evaluation with different traffic patterns is necessary.

The third metric is the scalability of wireless grids. A protocol that works well in a small network may perform poorly for a large network. Long-range communication is the key point for a scalable network. The scalability needs to be carefully analyzed,

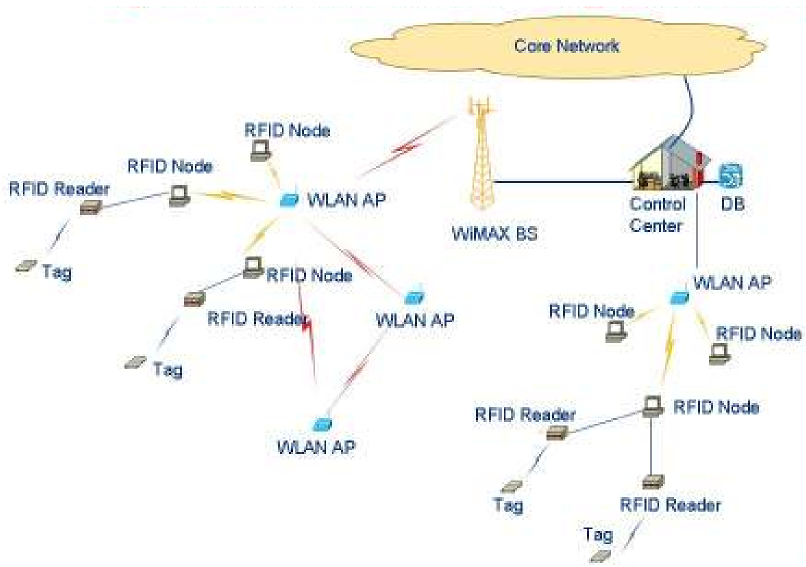

Fig. 4: Overall information service system for mega-event

simulated and evaluated. The other issues such as self-forming, self-organization, self-healing, connectivity and robustness must be dealt with carefully. Compatibility and interoperability with existing networks such as 3G, 802.15 and 802.16/WiMax are crucial to enable the connection to cellular systems, sensor networks and WiMax. Comparison of All-WiFi and WiMax-WiFi grids, as well as WiMax will be conducted to provide an insight of their characteristics and performance.

- **Routing for MCMI:** Routing is another important factor for scalability. Normally, routing protocols for ad hoc networks are modified for wireless grids. However, there are some significant differences between the two networks. The existing routing protocols treat all nodes in the same way, however, in a wireless grid, routing for NNs, SNs and HNs, as well as routing between them are different. Efficient routing protocols must be developed for satisfactory performance.

New routing protocols are needed for MCMI as not only a path but also a chain of channels is to be selected. A cross-layer approach is to be taken where we should consider MAC, routing, interface scheduling and channel assignment simultaneously. Load balancing among NNs, SNs and HNs are to be considered. Routing for directional antennas is to be studied. Various performance metrics such as link quality, RTT and ETX can be used to evaluate the routing protocols.

EXAMPLE

In virtue of the above networking technologies, according to the demands of RFID services and mega-event intelligent monitoring for EXPO information system, as well as the demands of ubiquitous broadband wireless access within the mega-event field, a novel wireless heterogeneous networking example based on WiMax-WiFi grid is designed and its network architecture is shown in Fig. 3.

WiMAX SS/CPE and the switches provide backhaul for WiFi APs respectively. Combined with WiFi Mesh networking structure, WiFi APs can be deployed within the flexibly in the mega-event field to achieve the ubiquitous WiFi coverage. This joint networking coverage solution is based on the mature mainstream technology, taking into account certain prospective.

Furthermore, RFID Reader and video cameras are used as detection equipment (support wired or 802.11 b/g standard) to complete the data acquisition, thus providing flexible, reliable and timely access for a variety of wireless communications services with different QoS requirements, where, WiFi AP provides backhaul for RFID Reader and video cameras (Harrison, 2004; Kulkarni *et al*., 2005). Based on the hierarchical wireless network based on WiMax-WiFi mesh configuration Fig. 3, the overall information service system for mega-event can be illustrated in Fig. 4.

Two kinds of RFID data acquisition and application services have been achieved in the overall information service system in Fig. 4:

- **Exhibit information acquisition:** Exhibit information has been stored in the RFID tag attached to the exhibit in advance, so the exhibit information, such as manufacturer, date, introduction and performance, can be read from the tag by RFID reader, which frees from the manual operations or UPC CODE scanning and avoids the general bottleneck of information acquisition. The information can be acquired automatically and with high speed, especially a multiple of tags can be read all together.

- **Exhibit management and searching:** When the exhibits arrive at warehouse site, the RFID readers at the entrances scan the tags attached to the exhibits, so the EXPO control center can know which warehouse a certain exhibit is in. Meanwhile, warehouse manager can using remote RFID reader to position and find a certain exhibit from a pile of exhibits in a warehouse.

In CSMA/CA mechanism, if a site is sending data while the other sites will detect that the channel is busy so that stop sending data until the channel is idle. Therefore, the data sending between the adjacent APs or sites tends to inhibit mutually. This is called RF interference. So it is necessary to analysis the distributed power control and load balancing in WiFi to guarantee the communication range, capacity, scalability and robustness of WiMax-WiFi mesh configuration.

RESULTS AND DISCUSSION

Distributed power control algorithm: Figure 5 indicates the communication range and carrier sense range, usually the carrier sense range is greater than the communication range. Site 1 in Fig. 5 is in the communication range of AP1 and carrier sense range of AP2. Due to the presence of interference, site 1can not normally access channel. In order to use the channel, the competition between sites exists. The increase of the number of competition sites will lead to a decline of the overall network throughput. However, to adjust the transmitting power of wireless sites may introduce more hidden sites, resulting in the deterioration of network performance. Therefore, a distributed power control algorithm for AP is proposed in this study to achieve the load balancing and the improvement of network performance.

This algorithm has the premises or assumptions as below:

- Wireless site detects the signal strength around the AP to select the maximum and calculates the received signal strength according to the ideal fading model. Only when the intensity is greater than the normal reception threshold, the connection between the AP and wireless site can be established.
- This algorithm uses Friis model when the distance between the wireless site and AP is less than the Crossover distance, or uses Two-Ray model when the distance is greater than or equal to the Crossover distance, where, $crossover\_dist = \frac{4 \times \pi \times h_t \times h_r}{\lambda}$.
- AP is as the data source and wireless site is as the reception end of data, but the specific data rate is determined by the respective wireless site, that is to say, the data rate requirements by the wireless sites are different (Chen *et al*., 2006; Li *et al*., 2012).
- The coverage corresponding to the upper threshold of transmitting power is 250 m.

Figure 6 shows the flowchart of the proposed algorithm. Each AP adjusts the transmitting power according to this process. In this algorithm, the actual throughput of each AP is simplified to be the number of

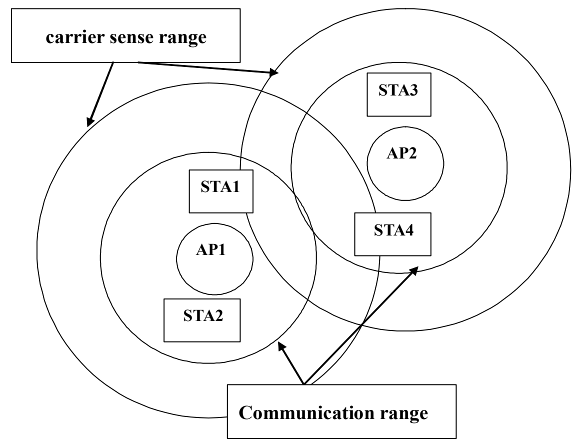

Fig. 5: Diagram of communication range and carrier sense range

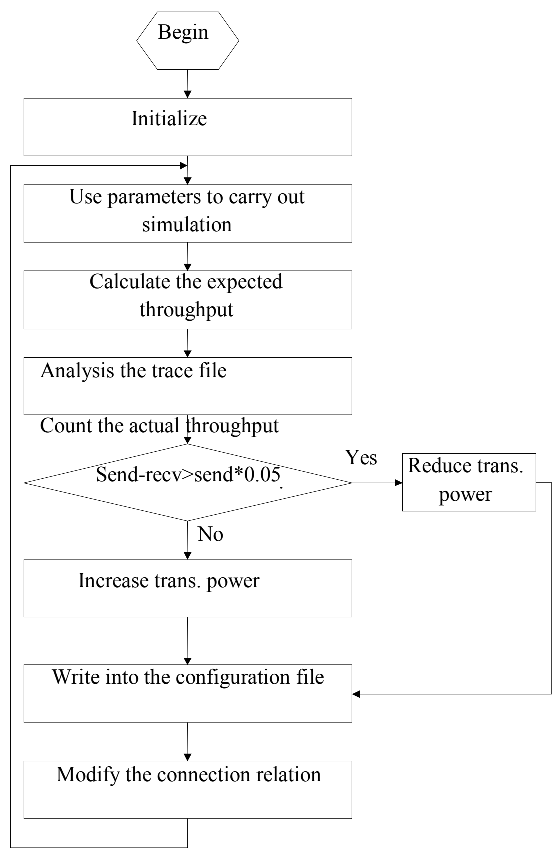

Fig. 6: Flowchart of the proposed distributed power control algorithm

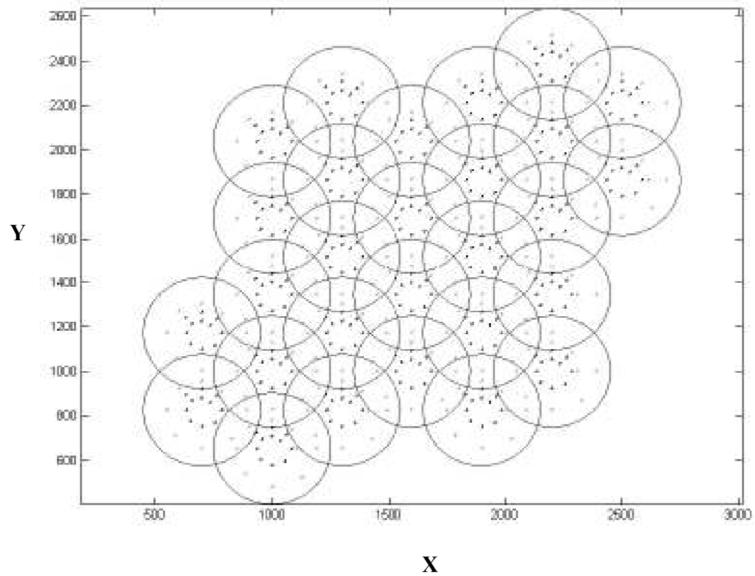

Fig. 7: Schematic diagram of AP coverage

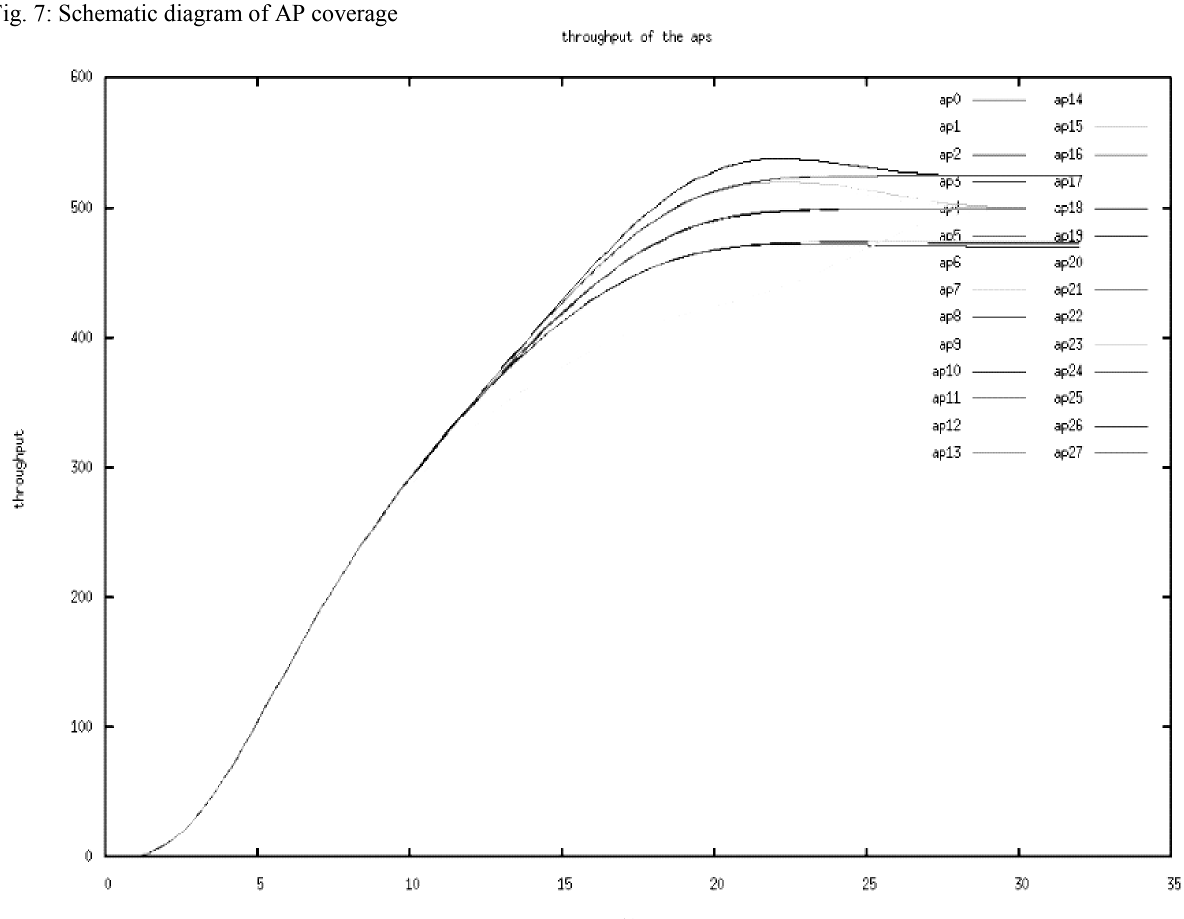

Fig. 8: Relation of actual throughput of each AP with the iteration numbers

ACK data packets received for each AP and the expected throughput is the sum of wireless sites connected to it. Determine to increase the transmitting power or reduce the transmitting power according to the relation of actual throughput of each AP and the expected throughput.

Table 1: Simulation parameters for the proposed algorithm

Parameters	Values
Maximum trans. power	0.2817W
Bandwidth	11M
RTS threshold	0
CS threshold	$1.559*10^{-11}$W
RX threshold	$3.652*10^{-10}$W

Distributed power control simulation: To verify the feasibility and efficiency of the proposed algorithm, network simulation software NS2 is used to build the simulation scenes in Fig. 7 and the simulation parameters are shown in Table 1. In Fig. 7, the sizes of the circles represent the AP coverage and the dots are on behalf of the wireless sites. 28 APs are deployed totally and 20 clients are distributed around each AP. In order to minimize the impact of hidden sites, RTS/CTS mechanism is used. In addition, according to the distance from wireless site to AP, the fading channel model in simulation selects the different formulas.

When the packet rate of each wireless site is required to be 10 Kbit/s, the simulation results are shown in Fig. 7. It can be seen that the transmit powers of each AP have reached the maximum and there is a certain degree of overlap. Due to the light load, there is not a serious mutual interference, so that 28 APs complete the seamless coverage of the region and the overall network performance is good. It needs to be noted that, all clients basically establish the nearest connection in this scene and the number the wireless sites around each AP are basically the same.

And Fig. 8 gives the change of actual throughput of each AP with the iteration numbers. It can be seen that the proposed algorithm can dynamically adjusts the connection between wireless sits and APs, mainly for the purpose of load balancing. The proposed algorithm is to optimize the performance of the network as a whole, rather than local optimization, so that it does not involve the information exchange among the APs and each AP carries out the distributed power control algorithm in accordance with its own throughput characteristics. The advantage of the proposed algorithm can be summarized that the convergence speed is fast, the control center is need not be set to reduce the additional information interaction, thereby increasing the use efficiency of network resources and lowering the computational complexity.

CONCLUSION

The wireless grid is emerging as an alternative to the existing Telco networks for local services. It has the advantages of good coverage, low cost and easy deployment, especially for the residential access network. It connects people to various resources. It will change the current network structure. In this study, we discussed the enabling technology as well as key research technologies of wireless grid in ubiquitous broadband wireless services for mega-event and illustrates WiMax-WiFi wireless grid networking example. As a key enabling technology for wireless grid, a distributed power control algorithm for WiFi AP is proposed in this study to achieve the load balancing and the improvement of network performance.

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