Chapter 2
Cooperative Mesh Networks

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2.1 Introduction

Rapid growth in wireless communication technologies have led to several networked technologies, like WLAN, WiMax, ZigBee, AdHoc networks, cellular networks etc. A new network architecture is required for convergence of the existing wireless technologies. A converged network having dynamic control over the network parameters and architecture is simpler to manage and operate [1, 2]. A wireless mesh network merged with the concepts of cooperative communication networks can provide an efficient platform for the convergence of these wireless technologies [3]. This convergence will also enable the network to realize virtual MIMO systems, which will further help to counter the effects of multipath fading, network latency, network robustness, and energy efficient operations [4]. Much work has already been done in the area of wireless mesh networks and cooperative communication networks. Let us have a brief overview of wireless mesh networks and cooperative communication networks and then we will discuss their convergence. We will also discuss MIMO systems which can be realized by such convergence.

2.2 Wireless Mesh Networks

Wireless mesh networking is a kind of wireless topology where not only each node is connected to every other in a wireless manner but also serves as relay for the other nodes for data communication. Wireless mesh networks typically consist of mesh clients, mesh routers, and gateways. Mesh clients can be typically cell phone/PDA

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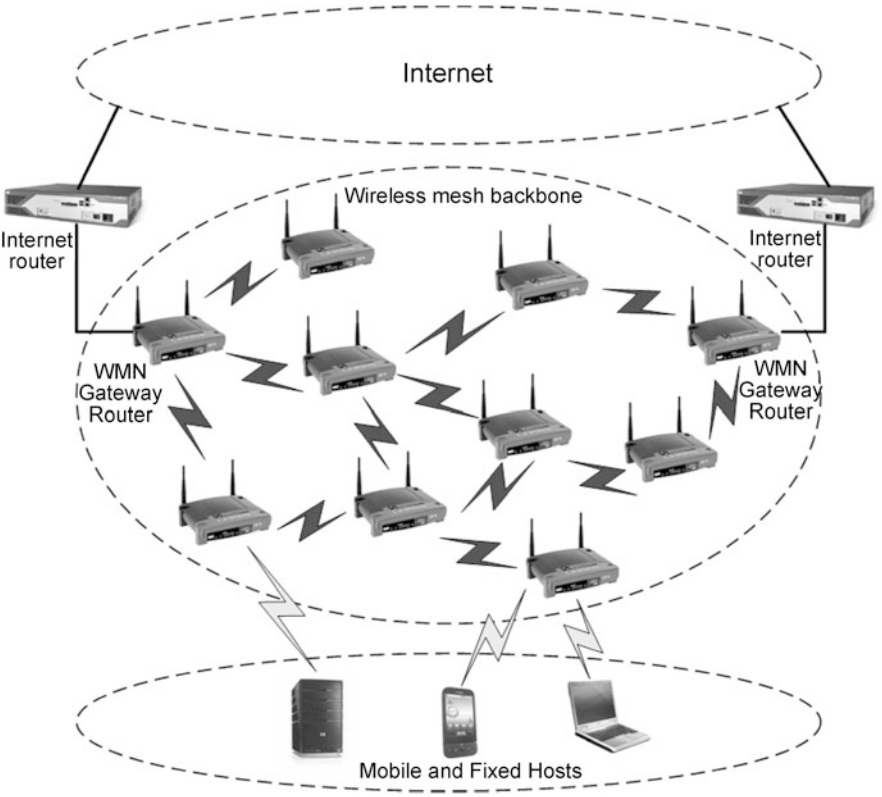

Fig. 2.1 Wireless mesh network [9]

users, laptop users and other wireless devices etc. Mesh routers forward traffic to and from the gateways. The coverage area of the radio nodes working as a single network is sometimes called a mesh cloud. The whole schematic can be seen clearly in Fig. 2.1. A mesh network is reliable and offers redundancy. When one node can no longer operate, the rest of the nodes can still communicate with each other, directly or through one or more intermediate nodes. Wireless mesh networks can be implemented with various wireless technology including 802.11, 802.15, 802.16, cellular technologies or combinations of more than one type [5].

2.3 Cooperative Communication

In cooperative wireless communication, we are concerned with a wireless network, of the cellular or ad-hoc variety, where the wireless agents, which we call users, may increase their effective quality of service (measured at the physical layer by bit error rates, block error rates, or outage probability) via cooperation. Figure 2.2

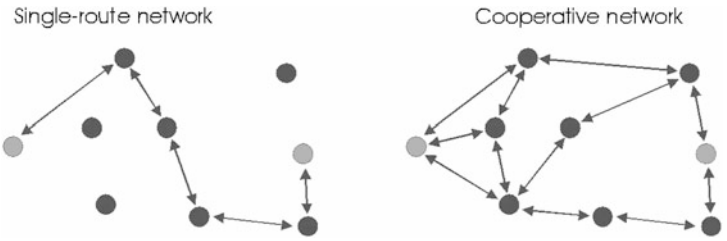

Fig. 2.2 Cooperative communication networks [10]

says in brief the underlying concept of cooperative communication. In a cooperative communication system, each wireless user is assumed to transmit data as well as act as a cooperative agent for another user. There are several methods of cooperation which allow single-antenna mobiles to share their antennas and thus enjoy some of the benefits of multiple-antenna systems [6].

2.4 Cooperative Mesh Networks

A cooperative mesh network is about a new architecture developed on the ideas borrowed from wireless mesh network and cooperative communication networks. The architecture consists of a wireless mesh backbone formed by mesh routers and gateways. The mesh clients in this case are several other wireless technologies, like sensor networks, separate wireless mesh networks with a gateways to this cooperative mesh network, Ad-Hoc networks, WLAN networks, cellular networks etc. The clients have to access the mesh router backbone in order to get connected to the gateways. Nearby clients can directly access the mesh router backbone to get connected to the gateway, while the far end clients can get connected to the wireless mesh backbone through multi-hop communication [3]. A simplified diagram in Fig. 2.3 makes the idea discussed above more clear about cooperative mesh networks.

There can be another simplified architecture for a cooperative mesh network which will consist of regular rectangular grids of mesh clients, mesh routers (possibly mobile) and mesh gateways. Every grid point is sampled for information (e.g. sensed variables), collected by a mesh router and transferred to the gateway. A suitable terminology for this cooperative mesh network shall be “mesh cloud”. The mesh cloud can be divided into regions that are covered by multiple mobile routers by considering any sub-region of mesh cloud and planning the path of mobile mesh router covering those sub-regions.

There may be fixed as well as mobile nodes in the cooperative mesh network, i.e. the mesh topology may be dynamically varying with time. This may be termed a dynamically reconfigurable network topology. In such a scenario the ability to control the network topology is very important.

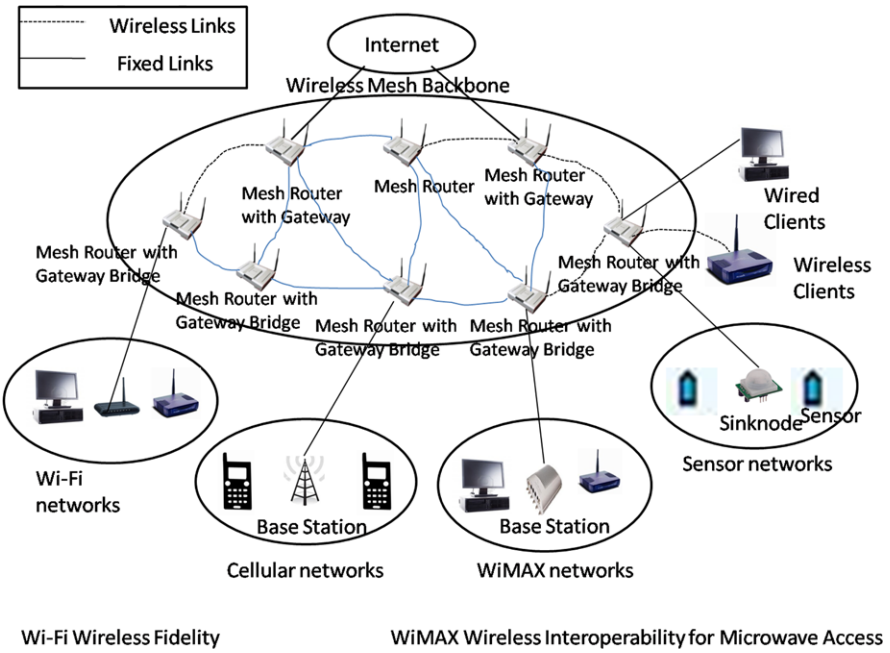

Fig. 2.3 Cooperative mesh networks [3]

2.5 Realizing Virtual MIMO

MIMO is the use of multiple antennas at both the transmitter and the receiver to improve communication performance in wireless scenarios. MIMO is an important part of modern wireless communication standards such as IEEE 802.11n (Wi-Fi), 4G, 3GPP Long Term Evolution, WiMAX, and HSPA+ [7].

It offers significant increases in data throughput and link range without additional bandwidth or increased transmit power. Improvement in MIMO communication promises performance enhancements over conventional single SISO technology for the same radiated power.

Hence if merged into a cooperative wireless network MIMO will be able to achieve significant improvement in network power consumption, latency, and network robustness. And also MIMO achieves these things without increasing the bandwidth of the system and without increasing the radiated power, which is one of the most constrained and scarce resources in a wireless network [8].

The "cooperative" nature of the cooperative networks makes them inherently suitable for the MIMO type communication. Let us see how a virtual MIMO system can be realized in a converged networks like cooperative mesh networks.

Though it is very difficult to get multiple antennas on the same node, be it a single node of a WSN or a cell phone user or a WLAN AP etc., if we see the whole network we have a good density of transceivers in a small area. So with the help of some intelligent synchronizing techniques we can couple a number of transceivers

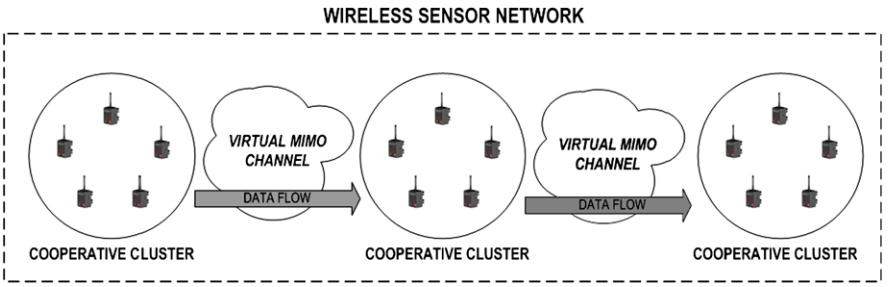

Fig. 2.4 MIMO with sensor networks [8]

(each with a single antenna assumption) and form a virtual MIMO network. Single nodes are constrained with respect to space; hence antennas cannot be placed wide enough to achieve spatial diversity. In a cooperative mesh network it is possible to create a virtual MIMO.

WSNs placed in the vicinity of each other can cooperate with each other to make a MIMO system. It can be either on the transmitter side or the receiver as shown in Fig. 2.4.

Several other combinations are also possible, like MISO (multiple input single output, where there will be multiple antennas at transmitter side and a single antenna at the receiver side), SIMO (single input single output, where there is single antenna at the transmitter side and multiple antennas at the receiver side. The desired MIMO configuration can be realized by dynamically changing the topology.

These configurations enable the network to achieve a very good spatial diversity as well as help achieving robustness. They also help in achieving energy efficiency.

2.6 Advantages

Some advantages which can be intuitively achieved with a cooperative mesh networks are as follows:

- Cooperative mesh networking will enable the choice of multiple paths between nodes i.e. clients, routers, gateways hence robust connections can be achieved. It will help to tackle the scenarios of node failures effectively.
- The ability to control topology also enables the option for "optimal" cooperative communication i.e. based upon understanding the environment (building, metallic objects etc.) the mesh topology could be finalized, to handle issues such as multipath fading.
- Mesh routers have a clear picture of the local topology; hence the node failures are easily detectable. In such cases a self-healing idea can be used to handle the node/link failure.
- Cooperative mesh networks inherently support scalability more than other existing wireless network architectures. Scalability will make the path of heterogeneous network convergence easier.

- Realizing MIMO will reduce the effects of multipaths as well as will lead to lower transmit power.
- Last but not least, it will thrust some more research areas like dynamic routing protocols and dynamically reconfigurable networks. Moreover application of cognitive radio is the other side of the coin whose application in cooperative mesh networks itself calls about a plethora of research issues.

2.7 Challenges

Realizing the goals above will require understanding the challenges in the design, implementation, operation, and maintenance of such networks. Some major challenges can be load balancing, routing, handover, security, centralized vs. decentralized control etc.

We expect seamless convergence/integration of different types of network, e.g. WLAN, ZigBee, WiMax, and wireless mesh networks.

Load balancing: Load balancing is about discovering and capitalizing the availability of multiple paths between source-destination pairs in the dynamically changing topology of network nodes. Path planning for mobile mesh routers i.e. multiple "mobile" mesh routers enable transferring information from and to the gateways.

Handover: There are two types of handover which have to be taken care of. Inter-mesh handovers where the mesh client can switch to another mesh router in the same network and intra-mesh handovers. Here the mesh client has to select the mesh router from another cooperative mesh network [3].

Routing: Routing protocols which can take advantage of multi-hop communication as well as being robust with respect to the inter-network and intra-network handovers in a converged heterogeneous network will be required.

Security: Security will be an inherent requirement because every data item has to be routed through the mesh routers to the gate way. There may be cases when there are some faulty or malicious mesh routers and hence they may disrupt the information flow. Also since the cooperative mesh network is made up of several heterogeneous networks, several suitable security protocols are required to run the network without any disruption.

Control: Dynamic control over the network (mainly network topology and network parameters) is an essential requirement. This control can be either centralized or distributed.

It is clear that different networks like WLAN, ZigBee, Internet, WiMax have widely different network parameters such as delay, jitter, bandwidth etc. In the integration of these networks, optimal delivery of different types of traffic (such as voice, video, and data) is very challenging. Providing quality of service to various types of traffic (e.g. multimedia) over different wireless networks leads to interesting challenges.

2.8 Conclusion

Convergence is the demand of ever growing wireless network technologies. It will make the network operations simpler and easily manageable. Cooperative mesh network indeed provides a generic framework for the convergence of existing wireless technologies. Through its concept of mixing the advantages of mesh networking and cooperative communication schemes it can handle a large number of wireless networks. It can also be scaled to handle even a larger number of networks. Advantages are coming from both the already matured wireless mesh networking technologies as well as widely used cooperative communication technologies. Further the application of cognitive radio technologies will add several advantages with respect to dynamic spectrum allocation as well as an increase in the QoS of the network.

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