beams can be formed on the basis of training sequences in the RTR and RTS packets and the same directional beams can be used for transmission or reception (which are reciprocal processes) for the entire duration of the DATA and ACK exchange. Also, MSs that are not attempting to receive data from others are listening for any RTRs that they may receive.

Each MS records the control information that it overhears from other ongoing transmissions, and uses this information to modify its radiation pattern by placing nulls in appropriate directions. This state information is maintained in a spatial null angle table (which is analogous to the network allocation vector of 802.11), that lists the transmitting MS, its radial direction relative to the MS maintaining the angle table, the time this entry was made, and the time after which the entry must be purged.

16.12 WiMAX and Major Standards

IEEE 802.16 is a set of standards on broadband wireless access (BWA), which was established by the IEEE standards board in 1999 and aims for global deployment of broadband wireless metropolitan area networks (WMAN). As currently defined through IEEE standard 802.16, a wireless MAN provides network access to buildings through exterior antennas communicating with central radio-based stations (BSs)[16.25]. Firstly, IEEE 802.16 aims to offer an alternative to cable-based access networks and address broad geographic areas without any costly infrastructure development required in deploying cable links to individual sites. Secondly, the fundamental design of the standard may eventually allow an efficient extension of the WirelessMAN networking protocols to individual users. It could accommodate such a connection with full quality of service (QoS) for nomadic and mobile users. In addition, IEEE 802.16 was designed to evolve as a set of air interfaces based on common MAC protocols but with physical layer specifications depending on the spectrum used and associated regulations. IEEE 802.16 should be developed with the P802.16 project authorization request with five criteria statements [16.94]:

- **Broad market potential**: It shall have the potential for broad sets of applicability, multiple vendors and numerous users, and balanced costs.
- **Compatibility**: While IEEE 802 defines a family of standards, all standards shall conform with the IEEE 802.1 architecture, management, and interworking documents.
- **Distinct identity**: It shall be substantially different from other IEEE 802 standards, having one unique solution per problem, and be easy for the document reader to select the relevant specification.
- **Technical feasibility**: It includes demonstrated system feasibility, proven technology, reasonable testing, and confidence in reliability, and coexistence of standards-specifying devices for unlicensed operation.
- **Economic feasibility**: It considers (1) known cost factors and reliable data, (2) reasonable cost for performance, and (3) consideration of installation costs.

16.12.1 IEEE 802.16j

IEEE 802.16j [16.95, 16.96] provides specifications to enhance IEEE 802.16s coverage extension and throughput enhancement by specifying a relay station. It specifies OFDMA physical layer and medium access layer enhancements to IEEE Standard 802.16 for the licensed band that enables the operation of relay stations (RSs). IEEE 802.16j MMR supports mobile multihop relay station (MMRS). There are three types of relay stations: fixed relay station (FRS), nomadic relay station (NRS), and mobile relay station (MRS). The network topology constructed by RSs could be either mesh or tree. Different from the conventional IEEE 802.16, MSs are able to connect to RSs. Due to the features of IEEE 802.16j MMR, it offers many economic benefits as follows:

- **Wireless backbaul**: RSs form the wireless backhaul and connect to the base stations. MSs can connect to any RSs and have data transmission with the BS by multihop fashion. The RS backhaul can be formed either with mesh or tree topologies.
- **Better trunking efficiency at aggregate points**: The traffic shall be aggregated to reduce the traffic load in the wireless backhaul.
- **Lower site acquisition costs**: MSs are able to connect to a near RS with lower transmission power for the uplink and higher SINR for the downlink. Alternatively, the data rate can be increased by multi-path routing and fault tolerance can be improved by multi-path redundancy.
- **Lower cost and complexity of RSs**: The cost and operation complexity of RSs shall be low so as to be widely deployed
- **Faster deployment**: the deployment of RSs is much easier than that of BSs, since RSs do not need wired connection. RSs can be easier to be deployed on electric poles or a building roof and have energy supplied by a solar panel.

16.12.2 IEEE 802.16m

This standard [16.97] amends the IEEE 802.16 WirelessMAN-OFDMA specification to provide an advanced air interface for operation in licensed bands. It meets the cellular layer requirements of IMT-advanced next generation mobile networks. The purpose of IEEE 802.16m is to provide performance improvements necessary to support future advanced service and applications, such as those described by the ITU in Report ITU-R M. 2072. The standard is intended to be a candidate for consideration in the IMT-Advanced evaluation process being conducted by the ITU-R.

- **Operating frequencies**: IEEE 802.16m operates in frequencies less than 6 GHz and is deployable in the licensed spectrum allocated to the mobile and fixed broadband service. The following frequency bands have been identified for IMT and/or IMT-2000 by WARC-92, WRC-2000 and WRC-07:
  - 450–470 MHz
  - 698–960 MHz

  - 1710–2025 MHz
  - 2110–2200 MHz
  - 2300–2400 MHz
  - 2500–2690 MHz
  - 3400–3600 MHz

- **Operating bandwidths**: IEEE 802.16m shall support scalable bandwidth from 5 to 40MHz.
- **Duplex schemes**: IEEE 802.16m supports both TDD and FDD operational modes. The FDD mode supports both full-duplex and half-duplex MS operation. In TDD mode, the downlink (DL)/uplink (UL) ratio should be adjustable. In FDD mode, the UL and the DL channel bandwidths may be different and should be configurable
- **Support for advanced antenna techniques**: For the BS, a minimum of two transmit and two receive antennas shall be supported. For the MS, a minimum of one transmit and two received antenna shall be supported. IEEE 802.16m shall support MIMO, beamforming operation or other advanced antenna techniques.
- **Support for government mandates and public safety**: IEEE 802.16m shall be able to support public-safety first responders, military and emergency services such as call-prioritization, preemption, and push-to-talk. It shall support regional regulatory requirements, such as Emergency Services (E9-1-1) and the Communications Assistance for Law Enforcement Act (CALEA).

16.13 Low-Power Design

The world today is moving from bulky computers to wearable devices. This shift in paradigm brings with it the need to think about the power conservation of the wireless devices, because limited energy resources characterize most wireless devices. Ad hoc and sensor networks today are in a nascent stage of development; however, when their use is commercialized, power consumption is expected to be a major hurdle in the smooth functioning of wireless nodes. For example, consider wireless sensors deployed in forests to detect the spread of wildfires. In this case, these sensors might be air dropped and might have to last for months [16.98]. Another example is ocean exploration to gather data about currents, tides, flash floods, and so on. In these cases, it is desirable that the devices do not run out of power at the crucial stage, because once deployed, replacement of their batteries is difficult and the only choice may be to replenish the whole sensor system. However, battery technology is progressing slowly, whereas computation and communication demands are increasing rapidly. To compensate for this, the scientific community is coming up with innovative methods to conserve battery power.

The traditional approach to saving power is to use power-down features to minimize the power consumption of unused hardware. For portable computers, this