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Title	**Mesh extensions to IEEE 802.16 and 16a**
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Re:	Proposal to include extensions to PHY and MAC to cover mesh systems with substantially directional antennas.
Abstract	IEEE 802.16 specifies an air interface for PMP systems operating in the 10 – 66 GHz frequency range. IEEE 802.16a amends 802.16 by adding the specification for an air interface for both PMP and mesh systems operating in the 2 – 11 GHz frequency range. There are a number of options for different applications and to cater for the wide frequency range addressed in the standard. A mesh option using omni – directional antennas was included. This paper proposes the extension of the 802.16 standards to include a mesh option with substantially directional antennas. This type of mesh has advantages in traffic and user capacity, spectral efficiency and coexistence with other FBWA networks.
Purpose	For consideration by the ad hoc committee on mesh extensions
Notice	
Release	
Patent Policy and Procedures	

Mesh extensions to IEEE 802.16 and 16a

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Introduction

IEEE 802.16 specifies an air interface for PMP systems operating in the 10 – 66 GHz frequency range. There are a number of options for different applications and different frequency bands. At the time that the PAR was written, mesh systems were not available. The standard did not therefore address this option.

IEEE 802.16a amends 802.16 by adding the specification for an air interface for both PMP and mesh systems operating in the 2 – 11 GHz frequency range. Again, there are a number of options for different applications and to cater for the wide frequency range addressed in the standard. It was possible to add the mesh option because this standard was defined later than 802.16, in a period when mesh technology has been appearing in the market.

In fact, there are a number of variants of mesh systems, for various frequency ranges and types of FWA operation. One type of mesh uses omni – directional antennas. There is also a type of hierarchical mesh where sectored nodes are used (for example with 3 sectors to cover the whole 360 degrees). An option of this kind is specified in 802.16a with the expectation that omni-directional antennas will be used. Another type of mesh uses substantially directional antennas. This type of mesh is useful over the entire 2- 66 GHz frequency range but is not specified in either the original standard or the amendment. Changes to both the PHY and MAC layers are appropriate to allow operation of this kind of mesh. Areas of the specification potentially requiring amendment are identified in this paper. Detailed proposals for implementation are also available for consideration.

Directional mesh systems

Since the scope of the IEEE 802.16 standard was defined, there have been significant developments in mesh technology. Mesh systems with omni – directional and with directional antennas have been specified, where the degree of directionality varies from sector – like to relatively narrow beam. By reducing the antenna beam width, the capacity and spectral efficiency of the system can be greatly increased, allowing large numbers of subscribers to be served with a relatively small amount of spectrum. In addition, it is advantageous to provide network – wide management of resources (channels, timeslots and antenna pointing directions) in order to maximise system efficiency and capacity and to support the maximum possible number of users. With suitably chosen parameters and efficient resource allocation, systems can be built that address mass – market applications, with low- cost and easily installed user premises equipment.

A mesh with substantially directional antennas has a number of advantages:

- Improved spectral efficiency,
- Higher user density for a given amount of spectrum,
- Improved coexistence,
- Possibilities for automatic interference avoidance,
- Costs more linearly related to rollout (faster payback).

A mesh system of this kind can operate in licenced or licence-exempt bands. Because of the improved possibilities for interference avoidance, licence-exempt band operation may be effective in reduced probability of inter–operator interference. Antenna systems for directional meshes can be of several types:

- Switched array of directional antennas,
- Electronically steered arrays,

- Mechanically steered arrays.

The optimum choice depends on the frequency band and narrowness of beam forming required to meet system capacity objectives. Also the means by which different systems manage operational issues rely on the antenna systems implemented.

Mesh systems with directional antennas are described in ETSI technical report TR 101 939 [1], which concludes that these systems offer significant benefits in performance, whilst at the same time offering improvements in coexistence (both co-channel and same area) when compared with more traditional systems. The excellent coexistence characteristics of mesh systems are also detailed in IEEE Recommended Practice 802.16.2 [2] (originally published in 2001and currently the subject of a substantial amendment to add new frequency bands and scenarios).

Mesh extensions to 802.16

In order to realize the benefits of directional mesh systems with in the framework of IEEE802.16 standards, some amendments are needed. These are partly to make use of the higher capacity and addressing range of such systems and partly to allow correct efficient overall management of resources within a network of dispersed nodes. It is believed that such amendments need only be of limited scope, so that the majority of the completed standard is still applicable.

It is therefore proposed that relevant parameters and procedures be added to the IEEE 802.16 standard, to include mesh systems using substantially directional antennas, covering the whole of the 2- 66 GHz frequency range. This will entail changes to both PHY and MAC specifications. Extensions to the standard proposed will be only those necessary to include the new features. These cover the following areas:

- Connection oriented mode of operation:
    - New procedures to handle multiple frequencies/ timeslots/ antenna pointing directions.
- Subscriber densities and scalability:
    - Facilitated by directional antennas with dynamic channel management and agility, supporting a minimum of hundreds of subscribers per square kilometre and totals of thousands per system,
    - Mesh scalability (minimum of a few subscribers and maximum of many thousands of subscribers within a single systems and all values between these limits, allowing growth from an initial small set of customers to very large deployments without system disruption),
    - Support for variable mesh densities (from low density of as little as 1 per sq km to high densities of 1000 or more per sq km and all values between)
    - Management and alarm scalability - dealing with high density and large systems as well as smaller and lower density applications,
    - Impact of antenna locations (on buildings) (procedures for selecting location and calculating the best use of resources based on this choice),
    - Unified mesh node identities across a large-scale system (to allow a single large network to be deployed).

- PHY extended for:
    - Use with substantially directional antenna systems,
    - Timing recovery – extended synchronization word,
    - Power control within a connection oriented environment,
    - Management of changes between different modulation schemes for mesh connections,

- Adding and deleting timeslots from a mesh connection,
- Sufficient resolution in the receiver to measure very short duration interference pulses,
- Physical calibration of thresholds for interference detection,
- Exploration and calibration timeslots supporting mesh entry and planning.

- Procedures for network-wide scheduling, to allow the full benefits of spectrum efficiency and capacity to be achieved:
  - ATM based option,
  - Allocation of resources (e.g. timeslots/ frequencies/ antenna direction) in a high density, high capacity mesh,
  - Interference handling. – (intra and inter system interference)Sub–mesh procedures for scheduling and management, necessary for different mesh elements to inter–work:
  - Dynamic adding and/or deleting timeslots.

- End to end connections via [up to 10] hops with QoS management using reservation procedures:
  - DFS/DCS support for QoS.

- Survey, installation and mesh entry:
  - Site establishment procedures,
  - Automated set-up,
  - Concurrent installations,
  - Installation within an interfered environment (for some markets only),

MAC messages for defining a *Welcoming Set* of nodes for survey and mesh entry of new nodes, (This may be in addition to mesh entry proposals proposed by *Cowave* in IEEE C802.16d-03/18[3] Here the *Welcoming Set* establishment is not defined).

- Node admission procedure,
- Line of sight verification (automated procedures).

Mesh Planning Procedures:

- Orientation determination for directional antennas,
- Mesh Colouring (applying timeslot/frequency/antenna orientation) – for a preplanned system,
- Synchronised mesh changes: entire mesh and peer node changes supported,
- Incremental mesh planning at installation and the ability for ‘parked’ installations.

- DFS and DCS (for some markets only)*,
- Billing, alarms, AAA, including privacy sub-layer,
- Services: *1 from N* path protection, inverse multiplexing of IP (Internet Protocol).

* The terms DFS and DCS may be confused, as they are sometimes used to mean similar things (e.g. in ITU terminology). We distinguish them in this paper on account of the different purpose to which each is applied. For the purposes of this document, we use DFS (Dynamic Frequency Selection) to mean a mechanism that can detect pulse – like interference and if necessary cause a move to a non – interfered channel. DCS (Dynamic Channel Selection) in this document means a mechanism that can detect more constant interference (such as that generated by another node or another BFWA system) and if necessary cause a move to a non – interfered channel/ timeslot. These two similar mechanisms can allow effective mesh operation in the presence of various sources of interference, thus further enhancing coexistence capability.

General coexistence and interference avoidance – DFS and DCS

Conformance to the WirelessHUMAN standard implies operation with the ability for coexistence. DFS/ DCS may be required in some environments both at mesh entry and following a power cycle event of an installed node. DFS/ DCS requires the monitoring of other frequencies other than the operational one as a means of rapidly moving and continuing operation on other frequencies. The support of MAC messages will be required as a means of providing information to other areas of the network on interference events. The standard defines some DFS messages. Procedures should be developed to support these DFS related MAC messages.

Specific MAC changes

Antenna Addressing

Mesh network configuration message 'MSH-NCFG – Xmt Antenna' should be 4 or 5 bits not 3 bits to facilitate 16 or more antennas per node.

Conclusions

Enhancements to the IEEE802.16 standard are proposed by way of a limited amendment to the published standard. This paper has highlighted the areas requiring some modification so as to allow the standard to cover mesh systems with directional antennas, increased capacity and improved coexistence capability. It is anticipated that these changes could be implemented relatively easily and quickly, thus extending EEE802.16 to include benefits of recent developments in technology.

References

[1] ETSI Technical Report TR 101 939; "Fixed radio systems; Multipoint to multipoint systems; Requirements for broadband multipoint to multipoint radio systems operating in the 24.25 GHz to 29.5 GHz band and in the available bands within the 31.0 to 33.4 GHz frequency range

[2] IEEE 802.16.2-2001; "Recommended Practice for the coexistence of fixed broadband wireless access systems"

[3] IEEE C802.16d-03/18; "Scalable Connection Oriented Mesh Proposal"

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