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Communications Alternatives for Smart Grids: The Integrated Approach

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SUMMARY

Telecommunications and Information Technologies have experienced an extraordinary growth with the apparition of the Smart Grid concept in the Power Utilities domain.

Smart Grid deployment will require a massive presence of communication devices using diverse media that is normally shared with other applications.

This paper will describe the importance of network architecture and the impact of transmission technology on the performance of the network.

The paper will be focused on the aspects of wireless networks with special interest to the case of radio propagation. Most systems recommended for Smart Grid applications, are off-the-shelf equipment that share the media with other services and other users injecting a traffic that is growing day by day. In this paper we describe the importance of implementing Point to Point links rather than multidirectional diffusion ones.

Cost optimisation and full accomplishment of the new challenges required by Smart Grid Technology, implies the design of a new devices which implements, in a compact form, multidirectional radio links integrated with optical interfaces and Ethernet switching functionalities.

KEYWORDS

Heterogeneous Wireless Networks, Wi-Fi, WIMAX, Radio-Propagation, Networked Radios, Interferences, Latency.

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1. INTRODUCTION

The energy challenges that Power Utilities worldwide face at present are changing the whole electricity supply chain: from generation, transmission and distribution; to the customer and consumption side. In a further step, energy optimisation across the domains of electricity, gas, and heat will be a further challenge. The drive for certain lower-carbon generation technologies, combined with greatly improved efficiency on the demand side, requires customers to be more active and to have more interactions with the networks. More customer-centric networks are the way ahead, but these fundamental changes will impact significantly network design and control.

With the massive intermittent generation steadily growing and increased in feed at the lower voltage levels, sophisticated methods are required to maintain the required technical level of network functionality and operation. For example, the balancing services, now carried out mainly by the TSO's, will in the future rely also on new market players in the DSO's and at the lower voltage levels. An adequate legal and regulatory framework with monitoring and control mechanisms will be required for that too.

Diverse Smart Grid Interoperability Panels worldwide accepts that the communications in the Smart Grid / Smart City concepts always establish that the communication media should be fibre optics and some kind of radio links.

The challenges of deploying a telecommunication network for a Smart Grid are:

- High data rates
- High scalability. The network will have to support hundreds of users/devices with a mix of services, some of them very critical and with real-time performance requirements surrounded by thousands of other network users
- QoS support
- Cost-effective. The Total Cost of Ownership of the network has to be controlled to maintain the economic sustainability.
- Interoperability of equipment from different vendors
- Service integration flexibility. The network has to be able to seamlessly integrate services of different nature, some of them very critical for the operation and stability of the system.
- Efficient frequency reuse
- Seamless mobility
- Cyber security. As the media is shared with the public in general and the network with external customers, proper cyber security architecture has to be planned and deployed.
- Flexibility. Due to the potential high volume of users and information to be transmitted, and the required long life-cycle of the network, it can be foreseen that new services will have to be integrated during the life of the network so its architecture has to be highly flexible.

Normally is often assumed that all of the above points cannot be achieved simultaneously.

In particular, in radio links is recommended the use of the actual massive deployed technologies. This approximation can be useful in a non-populated environment like rural field but may experiment a high degree of congestion in populated areas in which the use of the Information Technologies is massive as awarded by the Smart City concept.

2. RADIO IMPAIRMENTS.

The Smart Grid applications inside a Smart City will experiment a very high degree of interferences because the high density of transmitters present sharing the same radio-channels.

This high population of interfering transmitters are mitigated by the CSMA access system in which the receiver will synchronize with the desired transmitter a condition of the Signal to Interference Ratio at the receiver front end was enough to decode the incoming signal.

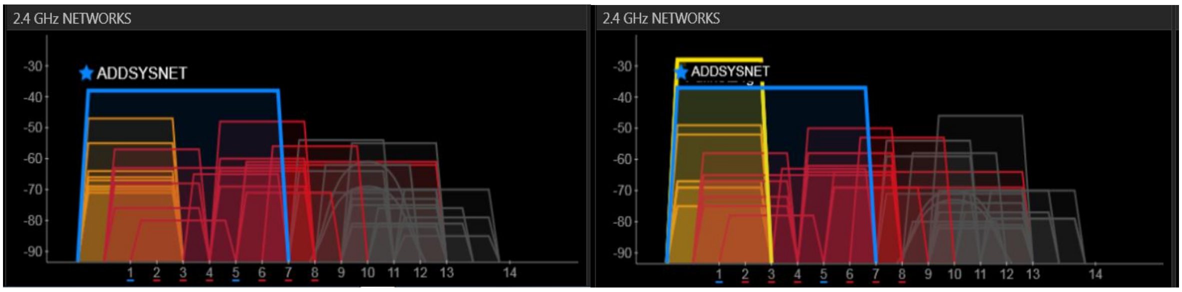


Fig. 1

The figure shows the spectra density in the 2.4 GHz band in one point inside the City. In the left graph clearly is indicated that the apparition of the emitter ADDSYSNET blocks any communication from this point to the red line transceivers. Only the channels from 8 to 14 can be used at this point. On the right figure it's represented other possible case of interference. Imagine that you are linked to ADDSYSNET emitter and other emitter starts in the vicinity, if the interfering is narrowband we only experiment a throughput reduction in other case our link can be cut.

3. NETWORK ARCHITECTURE, INFLUENCE OF THE TOPOLOGY

In the Smart Grid environment the data network is formed principally by static elements linked by radio waves immersed in a territory covered by a huge quantity of Hot Spots, Access Points, Mobile devices, etc.
Those emitters are completely uncontrolled mainly because those bands are free and anybody can look for connectivity.
In that environment every device fights to achieve connection with his correspondent. Normal strategies are change the TX power and also change the channel.

Depending of the applications running on the network a detailed analysis of the link, routing and topology implementation may secure the connectivity also in presence of strong emitters in the vicinity.

Because we are considering applications which requires a high range of data rates, It is not possible to design a uniform network capable to transmit all this data range at reasonably cost.

The classical approach to the network structures divides them in 7 groups as indicated in the next figure. Practical structures are a combination of these fundamental shapes.

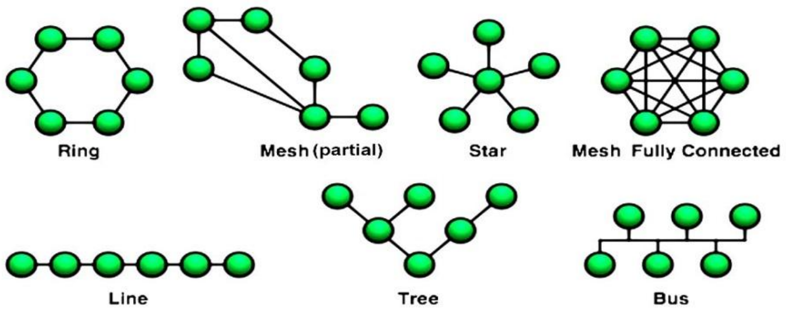


Figure 2

In Radio links and because the link is not a physical media, some of these basic structures have no meaning in this context. The most usual topologies are:

- Star. The most widely used in commercial Wi-Fi applications
- Tree. Commonly used in low density areas
- Line. Basically is a Point to Point architecture with 2 transmitters
- Mesh. Requires flow control and is not common because its complexity
- Ring. Technically possible but not widely used

With these structures there is possible to build 2 basic wireless modes:

- **Ad Hoc**. Independent Basic Service Set (IBSS); no need central Access Point, all nodes need to use the same SSID and RF channel. Not scalable mode.
- **Infrastructure**. Extended Service Set (ESS); needs AP allows the possibility to extend VLAN to wireless clients. Clients and AP must use same SSID, RF channel is set by AP and discovered by Clients. This mode is scalable.

As an example, the metering application, one of the most common in Smart Grid, does not require a great bandwidth for every device, but because the density of meters per km^2 in populated areas is very high, the topologies in three or double three are convenient because that allows the possibility to chain the meters towards the Concentrator.

4. PACKET RADIO SYSTEMS, WIFI AND WIMAX

In general, the radio systems are divided in two big families according its transmission system:

- Full duplex radios which uses separate frequencies for transmit and receive
- Half duplex radios which can share the same frequency for Tx and Rx.

Full duplex radios are widely used in point to point communication systems. Despite its complexity in the radio frequency part, the available band range from some Mega Hertz up to 100 GHZ with possibilities of public and private bands and the excellent throughput that can be achieved with this technology makes these radios the first choice when a large amount of information should be transmitted or the desired privacy is not accomplished with free bands.

Half duplex radios, alter named packet radios, are systems in which the RF channel is shared between transmission and reception parts. The possible interferences on the receiver coming from the transmitter are radically cut blocking the receiver during transmission and vice versa.

This procedure automatically cuts the possible data throughput but its simplicity and low cost makes the packet radios ideal for massive deployment systems.

Packet radio technology is the fourth major digital radio communications mode. Like the earlier modes, packet was intended as a way to reliably transmit data packets. The primary advantage was initially expected to increase speed, but as the protocol developed, other capabilities surfaced. In the Ethernet era packet radios are one of the simplest ways to perform the Ethernet data transmission in a wireless environment.

The International and National Frequency Band Regulators allocate some bands especially suitable for free access and packet radios. In that band, the Regulator only imposes a single rule which concerns to the power spectral density of the emitter (EIRP). This rule is intended to limit the transmission range allowing the possibility that many emitters share the same radio channels. Most popular of those bands are 2.4 GHz and 5 GHz in where the Wi-Fi, Wimax, Bluetooth, Zig Bee and other similar systems are deployed.

The most popular of the packet radios used today is the Wi-Fi system. The Wireless Fidelity is defined in the IEEE 802.3 group of standards.

In Wi-Fi networks, and considering the physical layer, all stations belonging to the same network share a single radio frequency communications channel. Transmissions on this channel are received by all stations within range. After decoding the received packets, upper protocol layers are in charge of process the information. The emitter uses the best effort delivery system and cannot manage any kind of packet acknowledge. In consequence there are more tasks for upper layers with its consequent delay variation.

Wi-Fi allows cheaper deployment of Local Area Networks (LANs). Also spaces where cables cannot be run, such as outdoor areas, electrical substations and other places where the cable deployment is costly or impossible due to the mobility of the devices.

A Wi-Fi signal occupies five channels in the 2.4 GHz band. Any two channel numbers that differ by five or more, such as 2 and 7, do not overlap.

The current 'fastest' norm, 802.11n, uses double the radio spectrum/bandwidth (40 MHz) compared to 802.11a or 802.11g (20 MHz). This means there can be only one 802.11n network on the 2.4 GHz band at a given location, without interference to/from other WLAN traffic. 802.11n can also be set to use 20 MHz bandwidth only to prevent interference in dense community but loosing throughput.

The Worldwide Interoperability for Microwave Access (WIMAX) offers an internet access point to point or point to multipoint or path and it is based on IEEE 802.16 group of standards.

The working method of Wimax is little different from Wi-Fi network, because Wi-Fi device can be connected via LAN card, router, or hotspot, while the connectivity of Wimax network constitutes of two parts in which one is Wimax Tower or booster also known as Wimax base station and second is Wimax receiver **(**Wimax CPE**)** or Customer Premise Equipment.
The Wimax network is just like a cell phone. When a user send data from a subscriber device to a base station then that base station broadcast the wireless signal into channel which is called uplink and base station transmit the same or another user is called downlink. The base station of Wimax has higher broadcasting power, antennas and enhanced additional algorithms. Wimax

technology providers build a network with the help of Point to Point and Point to Multipoint nodes using directive antennas that enable communication access over many miles..
The Orthogonal Frequency Division Multiplexed Access (OFDMA) in Wimax is a great technique used to take advantage from the frequency bands. The transmission frequencies of Wimax technology from 2.3MHz to 3.5 GHz make it low price wireless network. Each spectral profile of Wimax nodes may need different hardware infrastructure. Each spectrum contains its bandwidth profile which resolved channel bandwidth. The bandwidth signal is separately in OFDMA which is used to carry the data called in sub-carrier. Transmitted data divided into numerous data stream where everyone is owed to another sub carrier and then transmitted at the same broadcast interval. At the downlink path the base station broadcast the data for different user over uninterrupted sub-carriers.

Bluetooth devices intended for use in short-range personal area networks operate from 2.4 to 2.4835 GHz. Initially was standardized as IEEE 802.15.1 but the standard is no longer maintained. Actually is the Bluetooth Special Interest Group oversees the development of the specification, manages the qualification program, and protects the trademarks. To reduce interference with other protocols that use the 2.45 GHz band, the Bluetooth protocol divides the band into 79 channels (each 1 MHz wide) and changes channels up to 1600 times per second. Newer Bluetooth versions also feature *Adaptive Frequency Hopping* which attempts to detect existing signals in the ISM band, such as Wi-Fi channels, and avoid them by negotiating a channel map between the communicating Bluetooth devices.

The ZigBee communication system based on the IEEE 802.15.4 operate in the 2.45–2.4835 GHz band, and so are subject to interference from other devices operating in that same band. To avoid interference from IEEE 802.11 networks, an IEEE 802.15.4 network can be configured to only use channels 15, 20, 25, and 26, avoiding frequencies used by the commonly used IEEE 802.11 channels 1, 6, and 11.

IEEE standard 802.15.4 intends to offer the fundamental lower network layers of a type of wireless personal area network (WPAN) which focuses on low-cost, low-speed ubiquitous communication between devices (in contrast with other, more end-user oriented approaches, such as Wi-Fi). The emphasis is on very low cost communication of nearby devices with little to no underlying infrastructure, intending to exploit this to lower power consumption even more.

The basic framework conceives a 10-meter communications range with a transfer rate of 250 Kbit/s. Tradeoffs are possible to favor more radically embedded devices with even lower power requirements, through the definition of not one, but several physical layers. Lower transfer rates of 20 and 40 Kbit/s were initially defined, with the 100 Kbit/s rates being added in the current revision.

Even lower rates can be considered with the resulting effect on power consumption. As already mentioned, the main identifying feature of IEEE 802.15.4 among WPANs is the importance of achieving extremely low manufacturing and operation costs and technological simplicity, without sacrificing flexibility or generality.

Important features include real-time suitability by reservation of guaranteed time slots, collision avoidance through CSMA/CA and integrated support for secure communications. Devices also include power management functions such as link quality and energy detection.

5. RADIO PROPAGATION AT 2.4 GHz AND 5 GHz

Radio propagation path losses are not an easy matter to study and calculate. Till last century many mathematical models are proposed and some of them have demonstrated his validity in particular environments. None have full frequency coverage or full terrain adaptation.

Propagation models can be classified in different groups according its distance and frequency ranges. Normally the models for long ranges are simpler because the averaging factor of the distance over the impairments. Unfortunately, in the Smart Grid deployment, normally the radio equipped nodes shall to communicate at short distance with multiple wave reflections, high degree of scattering and aggressive interferences. In that environment a certain degree of reliability is required. So, a careful network design is fundamental.

ITU and National Regulator bodies have reserved some parts of the Electromagnetic spectrum as ISM bands (Industrial, Scientific and Medical). One of the most popular worldwide is the band around 2.4 GHz. Endpoints of this band depends of National regulations and, for instance, in India is from 2.4 GHz to 2.4835 GHz. This implement up to 13 channels, 22 MHz spaced.

In Smart Grid environment, the distances between nodes rarely are more than 1 km and for urban propagation, some popular propagation models should be discarded such as the Friis model and the two ray model which are specific for a long range. Other models like HATA and its variants also are not applicable because its validity ends at 1.5 GHz. Extension of the COST model from 2 GHZ to 2.4 GHz seems acceptable if we consider that the results will be optimistic.

The models based on the deterministic electromagnetic calculation, normally, are not expressed in terms of parameters that can be used in the simulation of wireless communications systems. Parameters such as delay spread, coverage, direction of arrival, and bit error rate (BER) are necessary for system simulations and need to be incorporated as part of the simulation code development.

Four different types of methods are often used in developing propagation models, and the above listed limitations are expected to impact them differently. For example, statistical models provide parameters suitable for system simulations but lack specificity and accuracy. EM-based deterministic models, on the other hand, provide accurate and site specific coverage and delay spread information but are also very computationally inefficient and time consuming. Empirical and measurement-based models are site specific, frequency specific, and hence lack generality. Researchers use a combination of these methods to help improve the accuracy, broaden the generality, and reduce the required computational time. But much more research and development are needed to fully develop accurate, computationally efficient, and experimentally verified propagation models that may be used for broadband and highly mobile communications systems. With the advances in the signal processing methods and the development of communications algorithms, the envisioned propagation models are expected to play a critical role in the accurate accounting for mobility and the dynamic variation in the characteristics of the propagation channels.

The 5 GHz Band has a wider spectrum available compared to the 2.4 GHz, 23 channels non overlapping in front of 3, which leads to significantly better performance as the 5 GHz is commonly used for usage that requires uninterrupted throughput in short range. The physics of the radio propagation establish that the power strength at certain distance decreases logarithmic with the frequency.

In the next figures represents the 5 GHz channel allocation in US and in the rest of the world

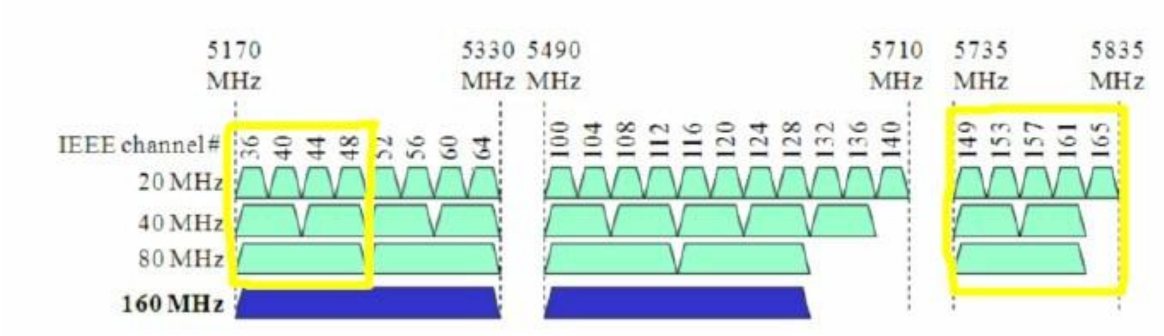


Figure 3. 5GHz channel allocation in USA

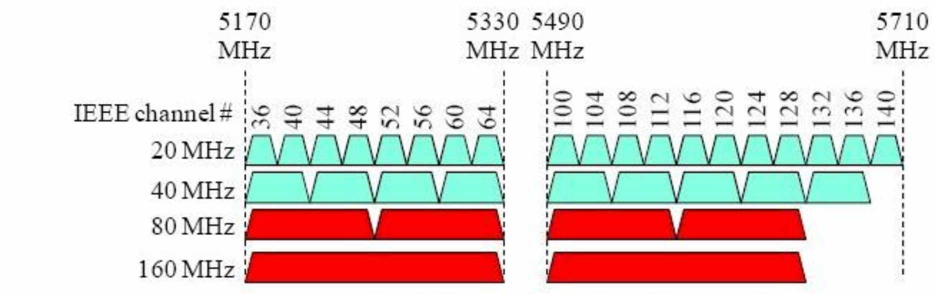


Figure 4. 5 GHz channel allocation rest of the world

6. NETWORKED RADIOS

The evolution of distribution electrical networks towards a higher degree of automation and protection as part of the forthcoming Smart Grid operative requires a telecommunications infrastructure capable of giving response to the new challenges and implementing the new services associated to a Smart City. That is, a city with a high energy efficiency, respectful with the environment and friendly with its inhabitants.

The integrity of the Electrical System and the quality of the service depend to a high extent on good operation of the Protection and Control systems. The associated Telecom infrastructure must therefore fulfil strict requirements with regard to robustness and availability in order to guarantee the high-performance signal transmissions necessitated, even in the worst scenarios.

To fulfil those requirements, a new generation of communication devices, Ethernet natives with multiple interfaces becomes necessary.

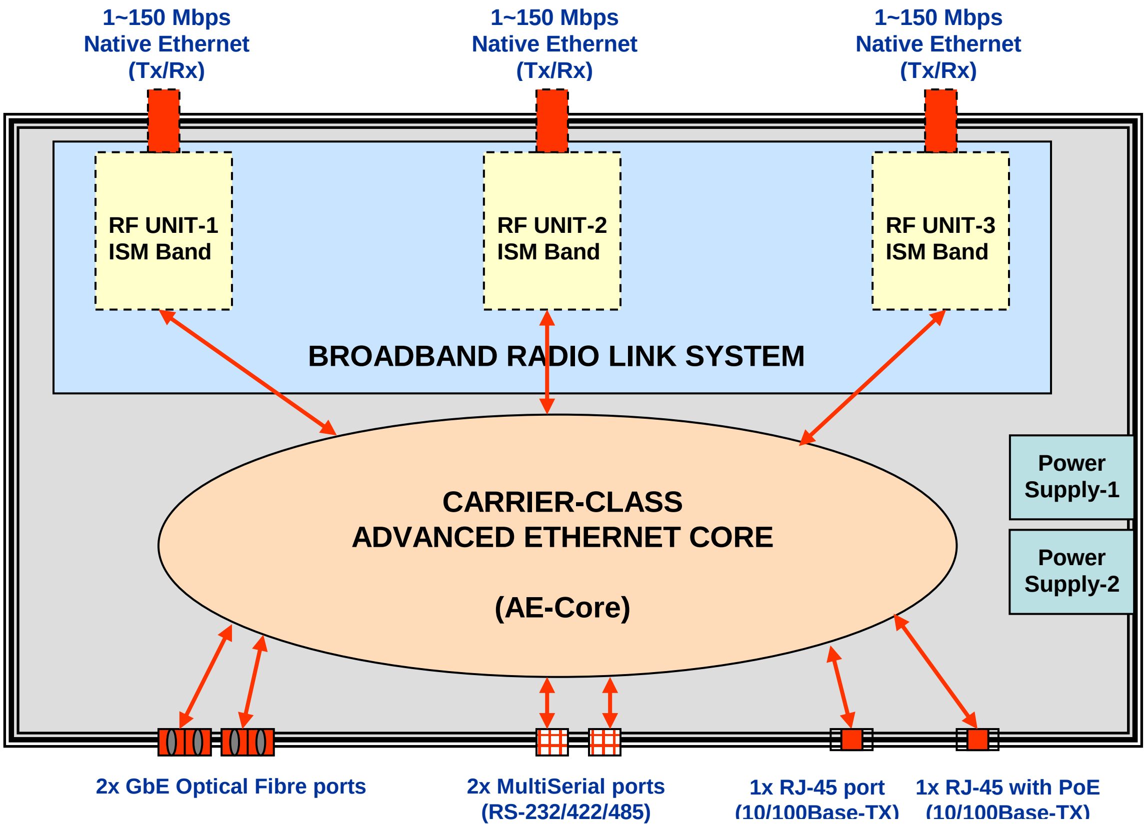
This new generation of Ethernet Base Stations (EBS) will combine high performance Wireless technology devised to establish broadband radio links that support native Ethernet frames with an Ethernet core that provides advanced L2 switching functionalities specifically designed to support the functionality and requirements of the new IEC 61850v2 standard.

By means of that EBS, carrier-class Ethernet networks can be easily and efficiently – also in costs – deployed even in *a priory* impracticable location, and then integrated into the Distribution Networks of Power Utilities.

EBS is capable of establishing point-to-point – and point-to-multipoint also – broadband Radio links. Thanks to its high performance switching technology which not only feeds the EBS-System with advanced Ethernet services for them to be transmitted via Radio Links, but is also able to extend such advanced services in the optically wired part of the Distribution network through Gigabit optical fibre ports, making it possible in that way proper implementation of communications networks dedicated to “Micro-Grids” that can support all kind of Smart Grid applications.

Having been specifically conceived to minimize transmission and switching latencies, EBS nodes may support generic real-time services thus providing optimum transmission of IEC 61850-compliant GOOSE messages.

The combination of hardware interfaces – i.e., high performance Radio links and wired ports (Fast Ethernet, Gigabit Ethernet and Multi-Serial RS-232/422/485) – provided by the EBS makes it possible to distribute the carrier-class Ethernet services across both wireless network and optical network.



7. CONCLUSIONS

Low Cost communication devices such as Wi-Fi Access Points and similar devices can be an efficient and cost effective solution in Smart Grid environment. Those devices will contribute to improve the bidirectional communication between them.

Other technologies like ZigBee seem to be ideal for metering applications but all of those devices share the same bandwidth.

Wi-Fi communications have improved its transport capacity in the recent years, IEC802.11n, with channel aggregation and its ability in front of interferences using multiple antennas and beam forming techniques. But, at least this technology needs to connect with the strongest signal.

EBS nodes are a good trade-off between cost and performance combining popular hardware, Ethernet Switch and Wi-Fi radios, with special firmware specifically developed for the Utilities and Smart Grid.

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