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SMART, UTILITY-GRADE WI-FI MESH FOR DISTRIBUTION GRIDS

by

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SUMMARY

All over the world, utilities are facing tremendous changes and challenges driven by deregulated markets, decentralized alternative power generation concepts and resulting Smart Grid requirements. Smart grids need a demanding and reliable 2-way communication infrastructure; not only to manage the backbone but additionally to secure supervision and control along the distribution lines down to the end user equipment including its power consumption & production behavior. Market deregulation has brought an increased cost pressure, the need to minimize aggregated commercial and technical losses (ATC) and on top of it contractual obligations for a defined service delivery performance.
To achieve these goals, a robust, high performing and cost-efficient communication infrastructure is required. Technically however, there is no unique solution that can be proposed, because each utility is exposed to very individual internal and external restrictions such as already existing infrastructure, network topologies, specific applications and, last but not least, legislation / market regulation.

The main focus of this paper is about wireless solutions for the distribution layer, particularly the use of Wi-Fi Mesh for utility-grade applications. It's a demanding environment where the various flavours of IEEE 802.11 standards need to be combined with special measures to comply with the utilities' and customers' expectations.

Key words: Wi-Fi, AMI, Mesh, ATC, wireless, distribution

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COMMUNICATION REQUIREMENTS FOR DISTRIBUTION APPLICATIONS AND COMMERCIAL TEMPTATIONS

One of the characteristics of traditional power networks is their one-way power-flow from centralized production down to the consumer. Modern networks however have to cope with plenty of decentralized, independent power producers generating bidirectional, fluctuating wind-, solar and other renewable energy sources. The increasing number of electric vehicles will in near future generate new peak load-profiles especially at the level of private consumers connected to the distribution-grid. Demand side management with sophisticated pricing schemes shall help using the resources in a well-controlled way optimizing the stability and reliability of power-supply for everybody.
Increasing commercial pressure forces utility to reduce the Aggregated Commercial and Technical losses (ACT). As an example: 'The 'Times of India'[1] talks about 35% of loss of the overall Indian production by theft, insufficient metering and outdated infrastructure. Various initiatives were taken especially focussing on sub-transmission and distribution level with the target achieving an ACT-rate < 15%.

To handle all the challenges on the way to a 'Smart Grid', not only the power-infrastructure has to be improved but also the communication especially at the Distribution Level of the network (→ DAN[1]). Low capacity one-way communication as punctually used in the past has to be replaced or enhanced by a bidirectional, preferably IP-based high capacity connectivity with a minimum capacity of 1Mbps. While some of the legacy services (e.g. AMR[2]) can operate with lower bandwidth are new applications like video-asset-monitoring and mobility support for maintenance work-forces calling for higher capacity and flexible connectivity.
High reliability and low latency are common with the requirements of communication solutions at transmission level.
In the past, many utilities deployed parallel low-capacity networks for the various applications, often based on proprietary UHF/VHF radio or other narrow bandwidth radio solutions that cannot fulfil today's requirements anymore. Fortunately, new, fully standard based wireless technologies have recently evolved. The majority of utilities are reluctant using public networks. With the upcoming LTE-technology, bandwidth targets may be met but doubts regarding reliability and availability for demanding utility applications prevail, not to talk about the high related OpEx. Interesting considerations can be found in [2].

[1] DAN = Distribution Area Network
[2] AMR = Automatic Meter Reading

Meanwhile ruggedized Meshed Wi-Fi solutions with standardized wireless interfaces and sophisticated routing mechanisms granting high availability are well established. Deployed as area/city-wide network, such switched/routed wireless Mesh can cover basically all operational applications of a distribution utility. In addition, it opens new business opportunities for a utility providing revenue generating Wi-Fi services to 3rd parties. The envisaged solutions provide all the means of traffic / QoS[3] control and service separation. A reference is given in later chapter of this paper.

HOW PHYSICAL CONSTRAINTS AND ENVIRONMENTAL IMPAIRMENTS AFFECT KEY PARAMETERS OF WIRELESS COMMUNICATION CHANNELS

This clause explains in a very generic and simplified way the theoretical and really achievable throughput of a wireless channel. Some details are derived from [3]. Understanding the basics allow making a comparison between wireless solutions that are based on a Point-Multipoint approach (e.g. 3G / 4G networks) respectively on a Mesh based architecture .

The wireless connectivity of devices bases on the fundamental fact that the maximum speed (throughput) that may be delivered to and from client devices (e.g. a mobile phone or a Wi-Fi enabled circuit breaker) depends on just a few factors, namely the bandwidth of the medium and the power (energy) present in the RF waves that is ultimately received by the receiver (→ received power). Mathematically this fact and the theoretical maximum capacity of a communication channel was formulated already 1948 by Claude Shannon and is known as ‘Shannon’s Law’ or ‘Shannon–Hartley theorem’

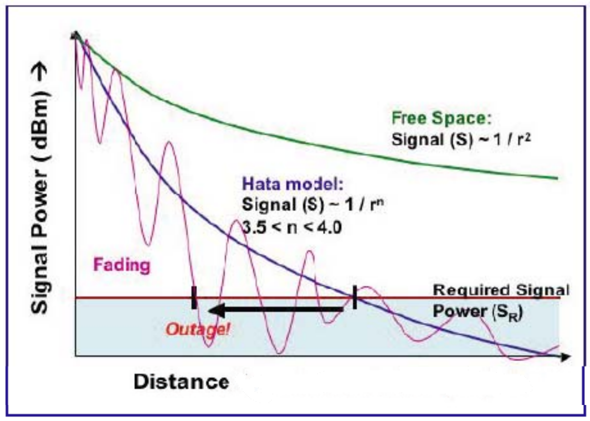
$$C = B * \log_2 (1+S/N)$$

C = maximum number of bits that can be transmitted per second
B = the channel bandwidth (Hz)
S = the power of the Signal received by the receiver (inW)
N = the power of the Noise present at the receiver, a function of B (in W)

[3] QoS = Quality of Service

As a matter of fact it says: to obtain a higher throughput one has to increase the channel width (use a wider slot from the very valuable / costly spectrum) or increase power @ both ends (limited by regulatory restrictions).
The only feasible way out for sufficient signal reception is to reduce the distance between the communication devices because the received power (S) decreases with the distance – theoretically under free space conditions as an inverse square law ($1/r^2$ where r is the distance → green curve in chart below. Closer to reality is to assume an attenuation according the 'Hata-model' where the signal decreases by $1/r^n$ with n = 3.5 … 4 → blue curve)

However, reality is more complex and RF waves may be reflected, scattered, attenuated or blocked such that the receiver receives a number of signals with varying power levels from multiple directions. The resultant signal is the sum total of all signals received. Therefore, in addition to Hata propagation, another phenomenon, known as fading causes the signal value to appear as if it is fluctuating randomly. The effect of fading is illustrated by the oscillating, violet curve and shows that link-outages may occur at less distance than theoretically expected.



Reducing space between nodes means more nodes per area. For typical Point-Multipoint systems this also means that each individual 'Master-station' has to act as gateway with corresponding backhaul connectivity (e.g. via fibre or Point-Point radio). A much more economic and at the same time very robust approach is therefore a Wi-Fi Mesh architecture. Few design considerations are given in the following chapter.

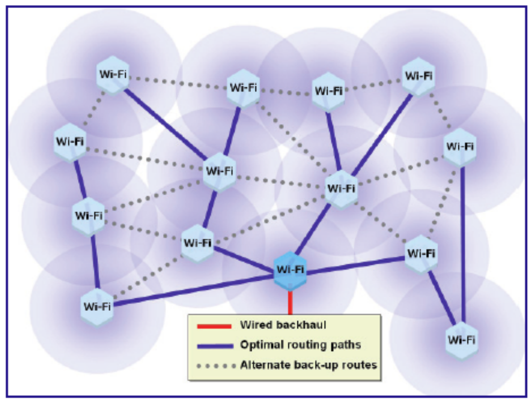
OPTIMIZED WI-FI MESH NETWORK PLANNING & BACKHAULING

Those familiar with wireless network planning (e.g. for 3G or even microwave-links) know about the challenges of backhauling, frequency- and throughput-planning, topology-considerations, interference and multipath-fading.

When designing a IEEE 801.11 Wi-Fi based network some of above mentioned headaches can be avoided when choosing a solution that not only operates in point-point or point-multipoint mode but that has enhanced Mesh and adaptive power capabilities.

For reaching the expected network performance one has to choose a technology where the nodes route the traffic in a smart way, without all the overhead of the traditional routing protocols. So called predictive wireless routing protocols (PWRP) overcome such deficits and make their routing decisions not only upon minimizing the number of hops but mainly based on:

- measured / verified bidirectional end-to-end service performance evaluation
- history- and trend-analysis of link performance
- predictive re-routing decisions



The adjacent figure shall illustrate how the current routing may look like. The network basically needs only a single Gateway connection (red line) towards the backbone/backhaul. For redundancy reasons, a second could be considered and will allow further, fully automatic optimization of the Wi-Fi Mesh.
Latest generation solutions simplify the network planning further as they select automatically an enhanced channel / frequency-scheme within the allowed / predefined boundaries (either 2.4MHz and/or 5GHz band). Due to that and thanks to some equipment inherent algorithms to adjust transmit output-power to the only required minimum level, network designers do not even have to care too much about system-caused interferences.

CASE-STUDIES: WI-FI BUNDLED WITH ELECTRICITY ...

For many of us continuous Wi-Fi / Internet access is meanwhile considered as a Must. Early adaptors to this trend established already ten years ago city Wi-Fi networks for public services and India's city of Mysore[4] was one of the very first places in the world who did so. At that time however, it was neither driven nor used by a utility but by a private initiative.

Meanwhile Wi-Fi Mesh technology has evolved and reached a performance level that allows utilities to use it at distribution level even for mission critical / operational services in parallel with providing services to the public. Means: municipalities / utilities sell not only electricity / water / gas as bundled service but add communication on top based on new business plans. One example is given in below case-study….

> **Raleigh, NC, March 27, 2013 –** [redacted] the leading power and automation technology group, today announced that Silicon Valley Power (SVP), the City of Santa Clara's municipal electric utility, has opened its [redacted] field area communications network to provide free public outdoor Wi-Fi access throughout its service territory. The network, based on technology and products from [redacted] wireless communication systems, was initially installed to provide communications for SVP's smart grid program, SVP MeterConnect℠. It is the first electric power Automated Metering Infrastructure (AMI) network in the nation to support free citywide public Wi-Fi access.

Silicon Valley Power (SVP) is a municipal utility that provides electricity to 52'000 customers across the city of Santa Clara, California, the heart of Silicon Valley.
SVP owns, operates and participates in 800 megawatts of electric generating resources and serves a peak load of approximately 470 MW. SVP also owns and operates a 100km fiber backbone that connects SCADA and 28 substations.
The deployed network of about 600 Wi-Fi Mesh nodes covers an area of 50km^{2} and complies with following performance criterias:

- Contiguous citywide wireless network coverage
- Peak performance: at least 95% of routers capable of delivering a minimum of 3 Mbps bidirectional peak throughput
- 100% of routers capable of 1 Mbps bidirectional simultaneous peak throughput
- Network availability better than 99.9% average
- Security: AMI-SEC System Security Requirements; NERC CIP 002-009, NIST Special Publication (SP) 800-53, NIST SP 800-82

Like SVP most distribution companies have excellent conditions for deploying a Wi-Fi Mesh as they can easily access assets for mounting the Wi-Fi devices. Low power consumption, meanwhile robust outdoor designs allow fast and simple installation.

[4] Location of Cigré-event where this paper was presented

CONCLUSIONS

Wi-Fi solutions with standard based wireless interfaces and smart meshing capabilities make this technology a viable approach to solve many of the typical challenges of communication networks at distribution level.

With sophisticated firmware algorithms used by the Wi-Fi Mesh nodes, network-planning becomes much less complex and allows utilities to deploy a network fast and smoothly. A network supervision and management system enables efficient analysis of traffic-performance, fast intervention in case of unexpected occurrences and eased network optimization. In conjunction with a robust, e.g. fibre optic based backbone a Wi-Fi Mesh is a very cost-efficient way deploying distribution oriented networks for operational and even for commercial use.

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