Wireless Smart Grid Communications

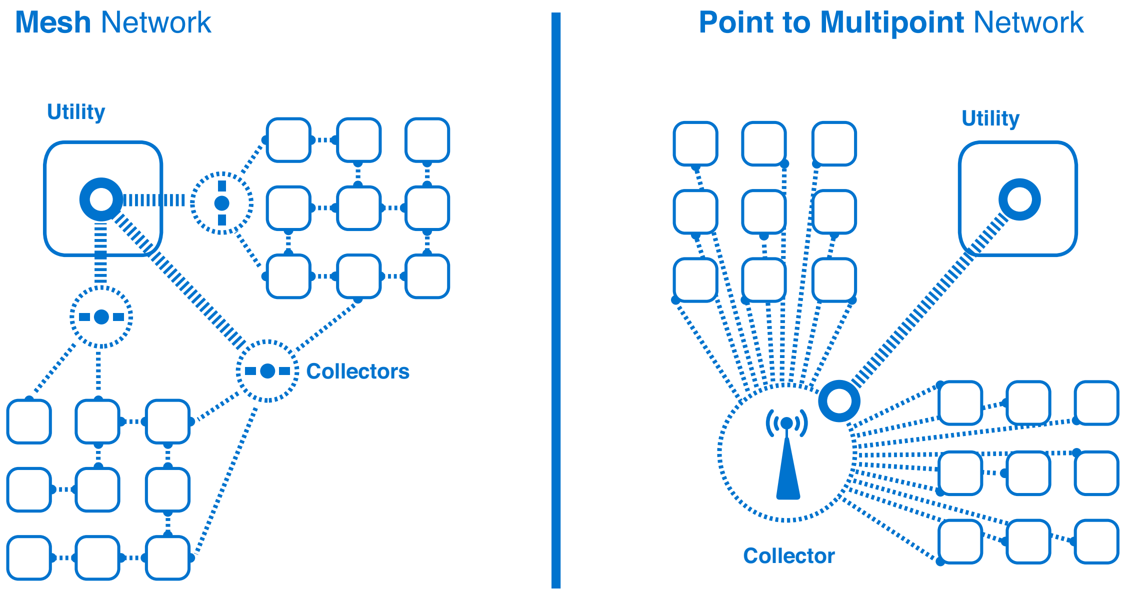
A Mesh versus Point-to-Multipoint Comparison

Two Approaches to Wireless Utility Communications: What Works Best for AMR, AMI, DA, and SCADA?

Utilities have discovered the benefits of wireless communications and now deploy them widely for Automated Meter Reading (AMR), Advanced Metering Infrastructure (AMI), Distribution Automation (DA) and Supervisory Control and Data Acquisition (SCADA). Two approaches have come to dominate the industry among electric, water and gas service providers seeking a backbone for their smart grid communications:

1. Privately licensed spectrum signals carried over a point-to-multipoint network architecture, and
2. Publicly available spectrum signals carried over a mesh network architecture.

The two approaches differ in architecture and signal type, yet both are used in all four types of applications. This paper provides guidelines for utilities selecting and designing their wireless utility networks. It will compare, contrast and evaluate the two approaches as they relate to real utility challenges. This paper will begin with a brief look at the two distinct architectural designs; then examine the wireless spectrum characteristics of each approach. Next, it will introduce the opportunities and challenges of wireless networking for each type of utility communications project: AMR, AMI, DA and SCADA. Individual charts will outline the evaluative criteria most important in assessing wireless communications for each application. Having thoroughly examined signal attributes, business and regional challenges, architectural impacts, and many other factors impacting wireless utility communications, the paper will conclude with a general recommendation to help buyers make smart choices when investing in a wireless communications network.



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Architectural Approaches

Mesh and point-to-multipoint are two distinct architectural approaches to two-way radio communication networks. In a mesh network, many radios (also referred to as endpoints) can talk to each other, peer-to-peer. Each point on the network can receive, store and transmit signals to other points in many directions. In a point-to-multipoint network, there is a "controller/agent" relationship in which a single point can talk to all the other points individually and they can talk back to it—but not to each other.

There are advantages and disadvantages to the two topographies and this paper will consider them as they can be applied to meet the needs of four important types of mission-critical utility communications: AMR, AMI, DA and SCADA.

Signal Transmission Characteristics

Privacy

All mesh networks all use unlicensed spectrum for their communications channel. They operate on public, not private channels. Often referred to as the industrial, scientific and medical (ISM) frequency band, this spectrum is shared with a wide range of devices including cordless telephones, baby monitors, and wireless Internet access modems. Internationally, ISM bands are defined by the International Telecommunication Union (ITU) Table of Frequency Allocations, in sections 5.138 and 5.150 of the Radio Regulations. Individual countries' use of the bands designated in these sections may differ due to variations in national radio regulations. Typical global ISM bands are 900 MHz, 2.4 GHz, and 5.8 GHz.

In the United States, ISM devices are regulated by the Federal Communications Commission (FCC) under Code of Federal Regulations 47 Part 15. Specifically, CFR 47§15.5 contains a general provision that devices may not cause interference and must accept interference from other sources. It also prohibits the operation of devices once the operator is notified by the FCC that the device is causing interference. Currently the FCC has type accepted (approved for use) over 9,000 different models of devices that can be sold and operate in the 902-928 MHz ISM band.

With these many devices operating without specific coordination or oversight, interference is not just probable, it is palpable.

On the contrary, licensed spectrum networks are private. Government regulators lease or sell use of an assigned bandwidth range which may only be used by a specific licensed user in a particular region. Interference is not tolerated within that region, and is protected by government agency enforcement, as noted above.

Signal-to-Noise Ratio (SNR) & Interference

Unlicensed mesh networks often have a high noise floor. A noise floor is like people talking during a movie; due to the number of voices being heard, understanding what's being said during the movie becomes more difficult. When industrial, institutional and medical devices are all sharing spectrum, the noise floor is high. With more devices "talking" above, below, and even on the same operating frequency, utilities that deploy a mesh system architecture face challenges in the signal-to-noise ratio because the public spectrum receiver sensitivity is reduced, causing signal to noise ratios to fall. High signal-to-noise ratios are ideal because they offer superior throughput and reliability. Unfortunately mesh networks are vulnerable to high noise levels generated in shared frequencies. This reduces the ratio and provides inferior throughput and reliability.

A common tactic to combat low signal-to-noise ratios is to reduce the distance between a transmitter and receiver in which an access point/collector can operate. Within a dramatically smaller operating area, endpoints are physically closer and signal-to-noise ratios are increased. Even if noise is prevalent in an area, stronger SNRs can overcome interference but with a significant loss of range.

Another approach to avoiding interference is to exploit access to a wide or large band by either: (1) sending a Direct Sequence, high speed transmission to disperse the signal across the band, much like a garden hose spray can be fanned out to a wide fast flow; or (2) Frequency Hopping, in which the signal switches rapidly from one frequency to another according to a pseudorandom code.

Licensed spectrum systems have a naturally low noise floor, maintaining excellent signal-to-noise ratios even across larger distances and in the presence of signals on nearby bands. And like an open highway, signal traffic can move swiftly and travel further than when plagued by congestion.

Range

Unlicensed mesh networks, being public, are prohibited from generating more than one watt of output, so their signals' range is limited. (This is the case in the U.S.; allowable power output varies from country to country and ISM band to ISM band.) Even if they could transmit further, they would suffer poor signal-to-noise ratios across longer distances. For these reasons, mesh networks locate many points close together and move signals across a larger area through a series of short range transmissions to intermediate nodes.

Licensed spectrum systems enable utilities to use higher power levels to optimize performance. Because of this flexibility, licensed spectrum networks are virtually interference-free and untroubled by crowded channels, as opposed to mesh networks whose power allotment largely relegates architecture to line-of-sight coverage only. Licensed spectrum signals routinely reach many times the distance of mesh signals.

Bandwidth Requirements

Unlicensed mesh networks use a lot of bandwidth for each transmission because the data 'hops' from node to node and requires a new slice of spectrum for each step. As such, the cumulative sum of bandwidth for sending a signal from its source to a final endpoint can really add up.

Licensed spectrum systems can work with a narrower band; however private spectrum is not as abundant as public spectrum. It's not free, either; but must be purchased or leased, sometimes in auctions where bidders must compete for licensed bandwidth.

Latency

Unlicensed mesh networks involve a processing step with each node they reach, and this slows the signals process to its destination. This lag or latency increases not only with distance but when there is traffic from voice communications or a high volume of other data.

In the example below, a 100 Kbps data stream is affected by latency issues. As data travels from endpoint to a collector via two nodes, the wide bandwidth is reduced to only 5 Kbps throughput. Assuming an average of only one hop, a theoretical 100 byte packet can be transmitted only 12 times a second.

The only way to reduce latency to improve data throughput is to reduce the number of hops but this means more backhaul. Mesh networks' backhaul typically consists of collectors connected to a DSL line, fiber, microwave or cellular 3G+ connection. Assuming a two square mile collector coverage area within a typical 400 square mile territory (20 miles by 20 miles), 200 collectors would be needed to support the entire territory. This would mean 200 broadband connections, one to each collector. Prices for backhaul will differ depending on methodology and system requirements, but for many sites, both costs and system complexity increase.

Licensed spectrum systems allow signals to move through fewer or no mid-point nodes, so processing time is minimal and the signal moves swiftly to its destination. Low latency, or reduced delay time, may be increasingly important in the data-heavy smart grid era of the 21st century.

Top Evaluative Criteria for Utility Communications Applications: What Matters and Why

What factors should utilities consider when planning their communications networks? Which should they weigh most heavily? Now that we've established the radio qualities and architectural considerations that differentiate each approach, we will note which of these and other top considerations most impact the performance of a wireless network.

The Top Factors to Consider Include:

1. Cost
2. Privacy and Security
3. Reliability
4. Redundancy
5. Range
6. Signal to Noise Ratio/Interference
7. Latency
8. Interoperability
9. Scalability
10. Resistance to obsolescence
11. Ruggedness in weather
12. Geographic challenges

Which matters most? It depends on your project requirements. Each of these factors is of varying importance depending on whether the deployment will be for an automated meter reading program, advanced meter infrastructure, distribution automation program or SCADA. This paper will consider the evaluative criteria for each program in turn.

Automated Meter Reading (AMR)

The basic improvement from reading analog meters by hand (and writing and sending written reports) to automated data gathering, whether by a walk-by or drive-by utility worker, can significantly increase operational efficiency, accuracy and control.

Which factors in wireless communications matter most when selecting a solution for an AMR program? The major criteria are charted on page 5, with an explanation of why each factor is weighted in importance for this particular application. While each utility will have unique needs that can impact the urgency of particular considerations, this chart is a simple way to begin sorting and prioritizing the factors needed for a successful wireless network deployment.

Advanced Metering Infrastructure (AMI)

When a utility establishes a fixed infrastructure—in which data moves from homes and businesses into utility operations and business processes systems (providing data to manage the flow of power and to inform billing and maintenance services)—it gains a platform for true smart grid applications. Equipped with real-time, two-way communications, utilities receive data at greater frequency and can use it to build improved customer service and to enable consumer participation in time-of-use pricing programs and other peak shifting programs that benefit utility and customer alike.

By eliminating the need for walk-by or drive-by meter reading, utilities can reduce their carbon footprint and the costs associated with training, insuring and transporting workers to meter sites. Utilities that provide a combination of services can streamline data gathering into a single system, delivering operational efficiencies, conserving resources and reducing or eliminating redundant and/or siloed data collection and communications systems for electricity, gas and/or water customers.

Which factors are most important to consider in selecting and deploying Advanced Metering Infrastructure solutions? The major criteria are charted on page 6.

Distribution Automation (DA)

Wireless communications in distribution automation unlock the intelligence of the grid by enabling real-time monitoring of a wide array of automation technologies across dispersed assets where physical communication lines would be costly to install and difficult to access for maintenance or monitoring. Wireless networks communicate with distribution automation assets including reclosers, capacitor controls, switch controls, faulted circuit indicators, voltage regulators, breakers and other status monitoring applications. Many routine operations that formerly required sending personnel to visit distant sites can be supervised from the operations center, allowing faster response to events. Engineers can view operations history and other historical data, such as load data from line reclosers, for improved system planning. Faster power restoration and greater efficiency and reliability in transmission and distribution efforts ultimately deliver results that build satisfaction among investors and rate payers.

The challenge of “last mile” communications is ideally treated with wireless communications, often providing utilities the first affordable and reliable link to remote substations. By strengthening this weakest link in utility enterprise communications, wireless networks help enable end-to-end smart grid operations.

Which factors in wireless communications matter most when selecting a solution for a distribution automation program? The major criteria are charted on page 7.

Supervisory Control and Data Acquisition (SCADA)

Wireless communications networks for Supervisory Control and Data Acquisition (SCADA) provide affordable, fast and reliable communications that work with any configuration or architecture. They help give “legs” to SCADA’s oversight authority. They add flexibility and can enhance security for SCADA when prudently deployed. Communications between a substation’s intelligent devices and control center SCADA provides essential data for multiple, simultaneous mission-critical operations, including protection, automation, control and testing; asset monitoring and management; remote configuration management; engineering access; and remote data collection and analysis.

Which factors in wireless communications matter most when selecting a solution for SCADA? The major criteria are charted on page 8.

Conclusion: A Buyer’s Guide to Smart Wireless Investing

The factors that affect a utility’s choice of a wireless network are highly influenced by the individual organization’s resources, goals and challenges. In practice, a combination of mesh and private/point-multipoint approaches may exist across a utility’s different applications or even within them as projects scale and grow. For example, a small metering mesh network may connect to a point-multipoint communications network for backhaul of data to a centralized control center.

Both approaches are based on open standards and can be scaled to grow. To maximize return and “future proof” an investment, avoid any network that requires all proprietary communications and lacks interoperability with other vendor solutions.

While private spectrum offers greater privacy, security, range, signal-to-noise ratio and latency, public spectrum is free and its topography provides innate redundancy. Consider the cost of spectrum and infrastructure installation as well as maintenance expenses throughout the lifecycle of the assets.

By weighing the factors outlined in this paper and building a business case carefully, utilities can select a wireless communications network that will fit their current budget and future needs, deliver equal or improved reliability and support long term customer satisfaction with rates and services.

Prioritizing AMR Considerations

Program Total Cost	High	Utilities need to show return on investment; most are able to make a business case for improved operational efficiencies, a reduced carbon footprint and improved customer satisfaction. The ability to roll out a program with the least intrusive infrastructure and minimal new equipment may be an advantage.
Privacy and Security	Medium	Rapid transfer of data into a handheld unit at a short range does not represent a significant increase in vulnerability of data compared to that of paper or online billing systems, but all programs must incorporate security protection policies that address identity theft and protect from malicious access to or sharing of personal information. Residents and commercial accounts will see less interruption, no in-home access needed with an AMR system. Consumers may appreciate the assurance of a wireless network in which their data transmits to a single point of communication with the utility and where their data cannot be transmitted to or received by other points on a local communications network.
Reliability	High	Reliability of new systems must meet or exceed pre-AMR achievement levels and anticipate the potential for future reliability mandates or standards. Not only does this impact consumer satisfaction, but it can run up costs through the need for potential retrofits and/or testing to meet any newly-imposed reliability standards.
Redundancy	Low	The presence of a person with every piece of transmitting equipment means someone is there to immediately address any communications gaps. Getting another unit is a simple fix that addresses redundancy needs.
Range	Moderate	Transmissions will occur over short distances from meter to handheld meter reading device. To assure reduced mileage and increased efficiency in data collection times, it is important to select offerings with optimal range with low interference, allowing data collectors to receive clear readings from as far as several blocks away.
Signal to Noise Ratio/ Interference	Moderate to High	In an urban setting, even if a meter signal travels only a single city block to the meter reader's handheld device or vehicle, there may be multiple potentially intrusive signals that could distort or delay efficient, accurate readings. In residential settings, the increasing level of wireless technologies in homes presents an additional potential source of unwanted noise. Selecting a communication network that meets a particular utility's tolerance for noise and interference is important to consider before deployment.
Latency	Low	When a utility moves from analog meter data collection to automation, the increase in speed and accessibility to data is exponential; the minor differences in latency between automation solutions pale in comparison to the gains of any AMR program.
Interoperability	Very High	A community's investment is more secure when a system can communicate with multiple meter brands that may already be present and with systems that may be used in the future. Readiness to read home energy management devices would also be a benefit consumers may appreciate.
Scalability	Variable	AMR is inherently scalable when interoperability is addressed as noted above. The importance of scalability may vary depending on utility needs and resources. Careful pre-deployment analysis of network configuration needs will help ensure that potential growth points are anticipated and that the system deployed is flexible enough to expand as needed.
Resistance to Obsolescence	Very high	Since AMR is often a region's first step into automated data collection and smart grid initiatives, satisfaction with the longevity of their investment and its ability to bring them future benefits is an important factor. Selecting rugged equipment based on open standards systems with high interoperability will help retain value on infrastructure investments.
Ruggedness for Weather Conditions	Moderate	Equipment must meet or exceed durability of pre-AMR options. Wireless networks can help drive customer satisfaction during power outages by delivering event news quickly to utility operations and potentially accelerating restoration. (Weather conditions include extreme heat, snow and ice, hurricane or tornado winds and flooding.)

Prioritizing AMI Considerations

Program Total Cost	Moderate to High	Utilities need to show return on investment; most are able to make a business case for improved operational efficiencies, a reduced carbon footprint and improved customer satisfaction.
Privacy and Security	High	Consumers value secure data. Equipment damage could create disruption of service and increase repair costs.
Reliability	High	Reliability of new systems must meet or exceed pre-AMR achievement levels and future mandates/ standards for increased reliability.
Redundancy	Moderate	Increased reliability may reduce need for greater investment in redundancy.
Range	High	Rural settings require great range; urban or suburban less so. In any scenario, greater range can mean reduced infrastructure costs.
Signal to Noise Ratio/ Interference	Very High	Vital in urban settings where commercial and emergency operations exist; in suburban settings where signals must be free from interference from home phone and Internet signals. Priority use of band could be a significant factor.
Latency	Low	Even with high latency, where signals may take a second or two, wireless communications bring vast improvement over formerly monthly availability of data.
Interoperability	Low to Moderate	Current AMR systems tend to be self-contained; however to accommodate interaction with future home energy management systems, this will become more important. IP-based systems offer greatest likelihood of future interoperability.
Scalability	Variable	Areas of historically slow growth will require less scalability than a rapidly expanding region.
Resistance to Obsolescence	Medium to High	Equipment should be designed to be upgradable using existing firmware, and should economically address future increases in bandwidth requirements so as to avoid obsolescence for years to come. In addition, the ability to have over-the-air programmability, whereby new features can be added without having to visit, let alone change out, the device, further improves resistance to obsolescence.
Ruggedness for Weather Conditions	Very High	Equipment must remain accurate and provide improvement in weather resistance over other choices. (Weather conditions include extreme heat, snow and ice, hurricane or tornado winds and flooding.)
Geographic Challenges	Very High	Urban metering must accommodate obstructions from tall structures; rural metering must overcome distances including ability to cross impassable terrain such as swamps, ice, rivers, cliffs, mountains, protected wildlife areas or farmlands. Suburban metering may require addressing infrastructure site scarcities.

Prioritizing Distribution Automation (DA) Considerations

Program Total Cost	Very High	The ability to bring in relevant, actionable data in a timely way from across an entire distribution system requires careful management of costs, whether for a large utility spread over a vast territory or for a small community's utility where resources may be limited. Efficient use of infrastructure and careful investment including total life-cycle costs of assets are vital considerations.
Privacy and Security	Moderate	While it is a given that both assets and the data they control need to be tamper proof and protected as much as possible, across the distribution system, security is more a concern than privacy.
Reliability	Very High	Distribution reliability is paramount. Wireless communications must offer enhanced protection of all system data through platforms that physically segregate applications such as AMI and DA yet allow efficient, cost effective delivery through shared infrastructure.
Redundancy	Moderate	The need for redundancy should reflect the particular utility's vulnerability to physical hazards and other factors, including historic performance, that impact electrical reliability. The need for communications redundancy is also affected by the criticality of each part of the distribution sectors that make up the full utility enterprise.
Range	Very High	Range is a vital factor in the selection of wireless communications. The total cost of a system is affected by the signal range of the chosen approach and the associated need for more towers and other elements of communications infrastructure.
Signal to Noise Ratio/ Interference	High	Mission critical communications cannot afford to take second place to the hundreds of other communications signals being transmitted. Utilities should weigh the availability of licensed private spectrum including priority privileges that protect utility communications from other signals that could interfere or diminish signal quality.
Latency	Moderate	Wireless communications that offer low latency and rapid signal transmission increase the availability of data to utility operations, where it can be optimized to enhance power efficiency.
Interoperability	Very High	To coordinate legacy controls and communications systems into a cohesive and flexible communications network, utilities should look for wireless networks that can "talk to everything" – as far as possible. Interoperability is a fundamental characteristic of a strong smart grid communications system.
Scalability	High	The ability of a system to begin small and expand as pilot programs prove themselves, funding becomes available, or urgent needs arise, is a significant consideration. Central control points which allow additional points to be added may be advantageous.
Resistance to Obsolescence	Very High	Deploying communications networks across an entire distribution area can mean investing in infrastructure on a large scale. The ability of a communications system to not only outlive the payment period for deploying it but continue to deliver ongoing or increasing return on investments is a vital consideration. Interoperability, scalability, total life cycle cost and ruggedness are additional factors that impact this quality.
Ruggedness for Weather Conditions	High	An advantage of a wireless network is that it can deliver data through weather conditions that are often unsafe for utility workers. A communications system that allows placement of equipment for least environmental vulnerability is valuable, as is one that offers the ability to select equipment resistant to any particular weather extremes typical to a utility's territory. (Weather conditions include extreme heat, snow and ice, hurricane or tornado winds and flooding.)
Geographic Challenges	Very High	Wireless networks offer the most cost effective approach to communications, allowing signals to rapidly pass through water, ice, construction zones, even protected or restricted private or government lands. Networks with the greatest range will be particularly effective in getting data across these conditions.

Prioritizing SCADA Considerations

Program Total Cost	Moderate	Any wireless system that increases the reach of SCADA is worth the investment. Compared to other methods of linking assets, particularly rural substations, a wireless option is a great value.
Privacy and Security	Very High	These elements cannot be underestimated. A wireless system for SCADA must be as unbreachable as possible. Wireless architecture that limits physical access, and wireless signals that grant exclusive access, may offer advantages. In many cases, private spectrum for wireless communications operate on the same bands once designated for SCADA.
Reliability	Very High	Essential. The wireless system's reliability must match or exceed the reliability of the SCADA system itself to provide mission critical data on demand.
Redundancy	Moderate	As a factor in reliability, redundancy can help to ensure that data has an additional route to travel if one is not available.
Range	Very High	The ability to use a wireless network to bring all assets into direct communication with SCADA control is vital. More than any other method, wireless networking can connect isolated assets. A wireless network with exceptional range may be particularly important depending on the geography and topology of a utility's dispersed assets.
Signal to Noise Ratio/ Interference	High	SCADA merits exclusive access to bandwidth without the risk of interference from unrelated noise.
Latency	Moderate	Signal speed can help when vast quantities of data are transmitted. Needs may vary depending on the volume of information in play at a utility.
Interoperability	Moderate	SCADA solutions are highly interoperable today but wireless networks also need the interoperability to connect to any and all distributed assets as well.
Scalability	High	Wireless networking needs to work in many scalable scenarios, whether it is simply connecting difficult to reach assets to augment an existing communications system or beginning or expanding a small network. Some wireless solutions deliver greater value on a larger scale, while others may help economize for more limited projects. These considerations and any future plans should factor into the decision of the best wireless network for a utility.
Resistance to Obsolescence	Very High	A wireless network can help extend the value even of older proprietary systems. When investing for SCADA communications, look for a wireless system that will retain value. Other factors include being standards based and not vulnerable to any increase in environmental noise that may come from future developments.
Ruggedness for Weather Conditions	High	Since the wireless system adds value by giving SCADA access to secluded substations or other assets, ruggedness is a factor in delivering ongoing reliability. It can also reduce the need to frequently repair or replace network equipment. Be sure to select a wireless solution with transmitters and receivers suited to the height, depth, moisture, heat, winds or other elements found in your distribution area. Consider how range and redundancy characteristics of a wireless system could affect performance in weather under emergency and ordinary scenarios, too. (Weather conditions include extreme heat, snow and ice, hurricane or tornado winds and flooding.)
Geographic Challenges	Variable to High	Geography can be a key factor driving use of wireless networking for SCADA. As noted above, careful matching of network characteristics and particular geographic challenges should be factors weighed in the buying decision.

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