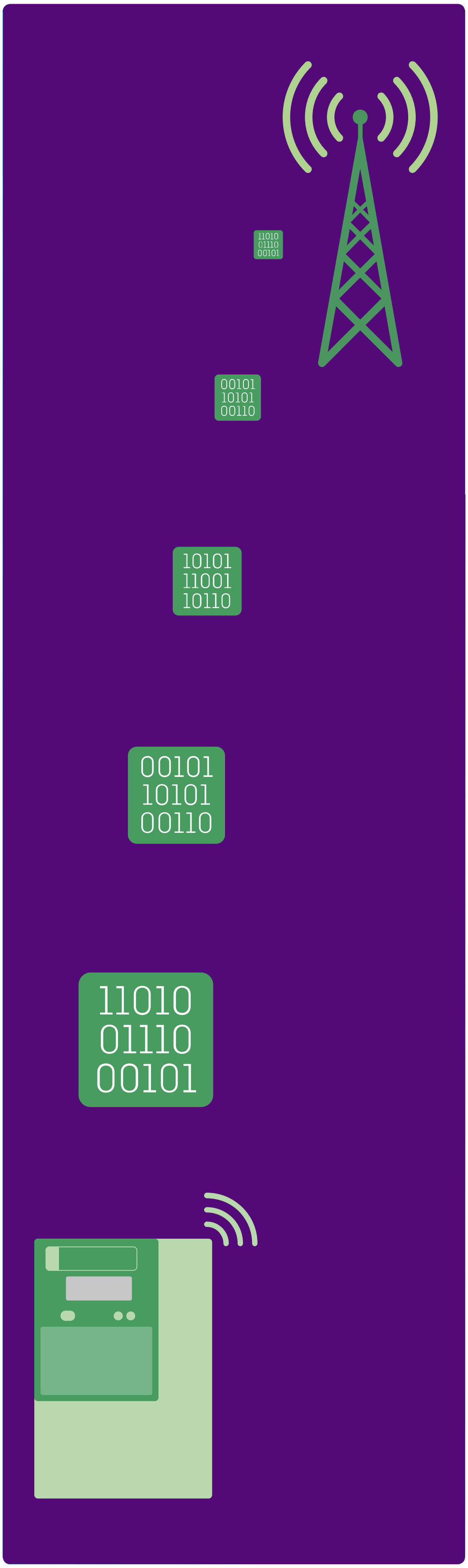
Wireless Communication for Smart Metering

Challenges, focus and expectations for battery-driven systems

To release the full potential of smart metering, the robustness and reliability of data are key factors to take into account when designing the metering systems of tomorrow



Wireless communication is expected to experience an exponential development in coming years. With this white paper, we seek to view this development in the context of smart metering and point to focus areas in coming generations of wireless communication for smart metering.

Having evolved from simple billing to intelligent metering systems, smart metering offers various services valuable to both utility and end user. These services have changed the requirements for the data extracted from the meters and with them the technological requirements for these systems. Robustness and reliability have moved into focus in order to ensure data quality while at the same time supporting an increasing meter population.

In the following, we will discuss the reasons for this change in focus and explore how this development within smart metering matches the development within IoT (Internet of Things) and wireless communication in general.

When it comes to meeting the future requirements for reliability and massive access, a vast array of options exists. We will describe those most relevant for smart metering and discuss their advantages and drawbacks. In recent years, several takes on the ideal IoT infrastructure have emerged, and when investigated in detail they all make use of one or more of the described methods.

Essentially, every design comes at a price, such as longer transmission times, the need for heavier processing, a more complex system architecture or more expensive components. Therefore, the choice of design becomes a question of balancing the specific functionality requirements for the smart metering application with the need for a dedicated smart metering infrastructure.

The future is now. IoT and the smart metering application

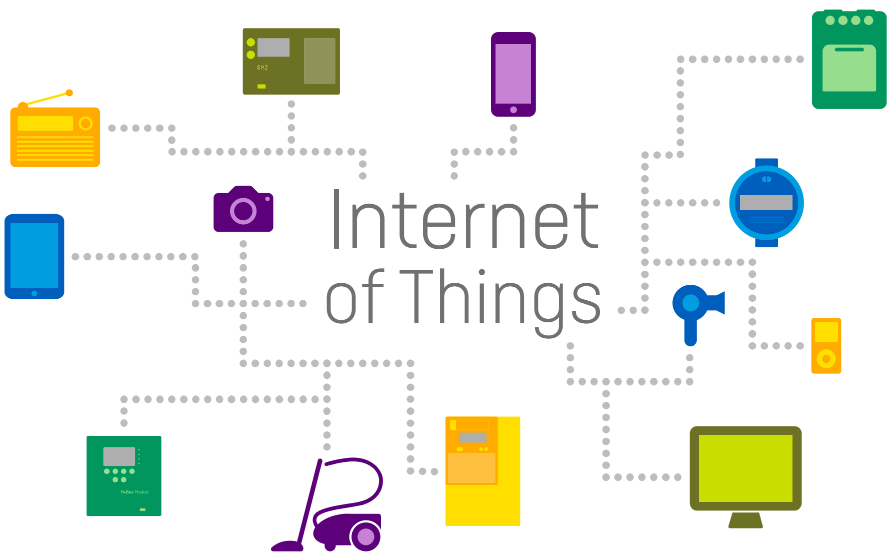
Already a reality, smart metering is a driving force in realising the IoT and represents an essential showcase for wireless communication in general, as they share both opportunities and challenges.

A major trend of the current age is the increasing interconnectedness of the physical and digital world. Hence, the emerging IoT paradigm is progressively becoming a reality. An increasing number of objects from our daily life are already connected to the internet and with the development within integrated circuits constantly driving down the cost of radio transceivers, even disposable objects, such as milk cartons, will be perceptible in the digital world. As such, the IoT is a vision of a world where (almost) everything is connected to the internet in one way or another.

And what does that mean? Firstly that by collecting data from myriads of devices and objects, we will be able to interact with our surroundings through data mining and detailed analytics with the aim of e.g. limiting energy consumption, preserving resources or simply having electronic devices around us operate according to our preferences.

Smart metering is often seen as one of the driving applications in the pursuit of making IoT a reality, one of the reasons being that its potential benefits with respect to data analytics covers both economic and environmental aspects. Also – and more importantly – there is already a critical mass of devices distributed in the field; something that is not the case for many other applications. In other words, this application is not a thing of the future; it is already here.

For a more detailed overview of how IoT is expected to drive further development of the smart metering application, check out our white paper *The digital water utility.*



Massive access and ultra-reliable communication

The IoT reality brings a completely new set of challenges for connectivity and communication technology. For decades, cellular communication has been the number one application to spur development within wireless communication technology and raise the bar with respect to the capacity of the wireless link, in terms of the achievable data rate and supported number of users, the main driver having been to meet the increasing demands from cellular use cases.

However, the requirements from IoT applications are fundamentally different from those of cellular communication. In an IoT context, the devices usually only need to communicate small amounts of data, maybe only a few times per day, but hold a battery lifetime of several years. For smart meters, a lifetime of more than 10 years is required. Moreover, they are often located in harsh conditions in terms of radio propagation, e.g. in deep indoor environments in stationary installations.

In spite of this, the next generation of the cellular standard, referred to as 5G, is being designed to embrace both the IoT paradigm and to meet the increasing requirements from cellular use cases.

As a result, three main challenges have been identified for 5G [1], namely extreme data rates, massive access and ultra-reliable communication.

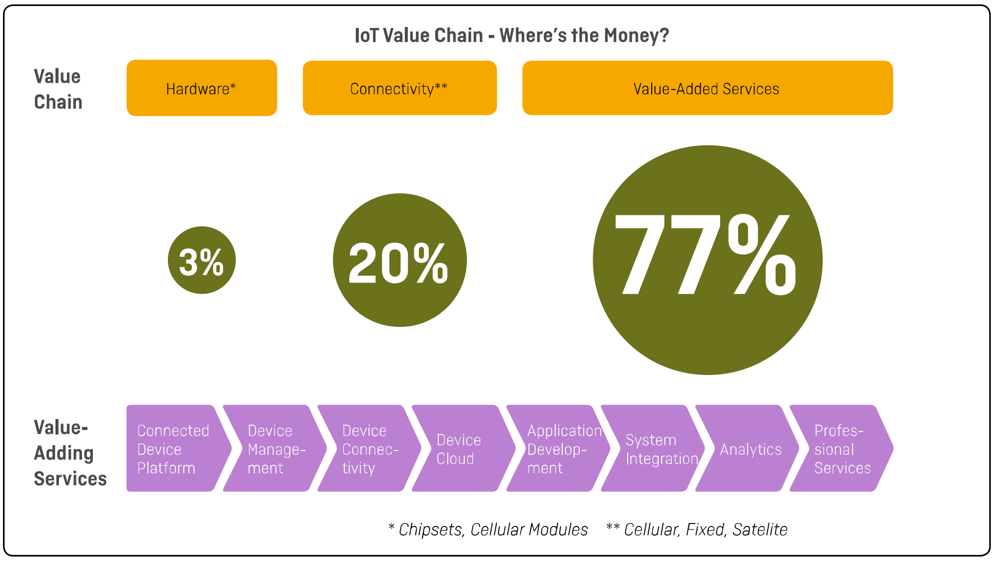
The latter two challenges are shared by the smart metering application in terms of meeting future requirements from utilities, making it relevant to draw inspiration from the development within cellular technology. However, the need for low-power operation in order to meet the required lifetime for smart meters limits the options for solving these challenges.

From an IoT infrastructure perspective, smart metering, with its stationary deep indoor installations, represents an essential showcase in the sense that if an infrastructure can support the requirements of smart metering it will be suitable for most IoT applications. Moreover, as with most other IoT applications, the main business case in smart metering is the data collected from the meters. In the following section, we describe options for analysing this data and extracting information that goes beyond just billing purposes.

From billing to services – the potential of data analytics

For utilities, detailed analytics carry a plethora of opportunities, not only in the form of economic results but also environmental benefits and improved customer service.

Expected Value Distribution for the IoT



The utility market has evolved from delivering a resource to also delivering a variety of services all founded in the data collected from the meters in the field. The evolution of technology allows for more frequent reports from the meters, which in turn opens up new opportunities for the utilities.

The value-adding services are based on advanced analytics and cover several aspects of interest for the utility, mainly within the areas of operational expenses (OPEX) and Corporate Social Responsibility (CSR).

Reducing production and distribution costs

For water utilities, one of the main concerns is non-revenue water (NRW), which is basically any unmeasured water that is lost in the distribution network [2], due to, for example, pipe bursts or leaks in the network or at the end users' homes.

By carefully monitoring the water flow in the pipe sections of the distribution network, a water utility will be able to identify and to some extent locate leaks. Furthermore, with sufficient data a utility may even be able to predict which pipe sections require maintenance and thus proactively prevent bursts. Such measures will help to reduce NRW significantly.

Moreover, detailed knowledge about the consumption pattern in an area will allow a district heating or water utility to schedule the production according to demand, the way we know it today from power utilities.

This allows utilities to level out peak loads and, particularly for water utilities, to adjust the pressure in the distribution network. This reduces the amount of energy needed to run the production and the distribution network (for pumps etc.).

Learn more about how detailed knowledge about the distribution network can be transformed into optimisations and results in our white paper *Monitoring Pressure in the distribution network.*

Helping the greater good

Besides their role as distributors of heat, water and electricity, utilities share a responsibility for managing resources with care for the sake of all of us and with detailed analytics of meter data they can do just that by helping end users reduce their environmental footprint.

Based on knowledge about the consumption pattern a water utility may advice a consumer to have a running toilet fixed, or suggest shifting non-time-critical activities like washing clothes to less expensive times of the day. A district heating utility may provide consultancy help for energy optimisation of the home to ensure a more efficient use of the district heating.

Initiatives like these have the potential to reduce the use of energy and water while at the same time saving money for the consumer. Of course, providing such services also carry an economic incentive for utilities all as they have a positive effect on the production costs as well.

Moving beyond just communication range

The new requirements for smart metering systems have sparked a broadened perspective that include not only communication range but also the robustness and reliability of data needed to ensure the required Quality of Service (QoS).

As the economic potential of the value-adding services exceeds the production cost of energy and water, data is subject to still more rigorous demands.

As a rule of thumb, the requirements for data quality increase with the complexity of the service. Data quality, or Quality of Service (QoS), can be viewed in terms of granularity, completeness or latency depending on the service.

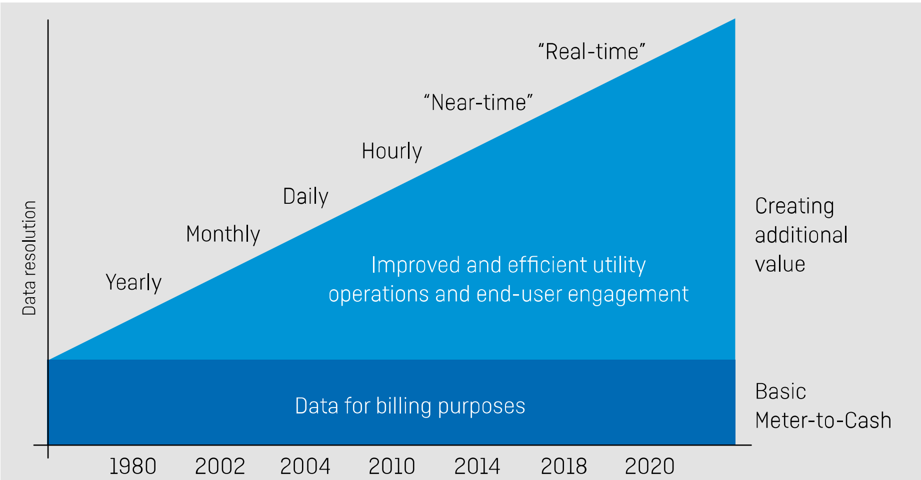
The clear tendency among utilities is a shift in focus from communication range in itself as the single parameter of interest to looking at range in the context of the required QoS. This may not sound like a great difference, but depending on how the target QoS is defined, the resulting range can be a few hundred meters or several kilometres. As an example, there is a big difference in the acceptable number of missed transmissions when a system must guarantee hourly data samples with 99.8% compared to just a single sample per month.

While range in itself is secondary to the QoS requirements, it still matters insofar that a long range helps reduce the amount of hardware in the field.

The smart metering market is highly competitive and the Total Cost of Ownership (TCO) of a system is essential when tenders are won or lost.

When it comes to system design, the requirement for a high level of QoS translates into a high level of reliability. The physical environment will always influence system performance due to topography, structural mass, land cover and static and mobile objects in the signal path. There are different ways of mitigating this influence and achieving reliability and robustness on multiple levels in a communication system. In the remaining part of this white paper, we will take a closer look at the options.

Development in Data Requirements



Cutting through the clutter

Challenges include both the impact of the surrounding environment and the limitations of the wireless medium itself in a time when the amount of IoT applications and devices never ceases to grow.

The design of future smart metering systems must navigate a number of limitations and challenges, something that calls for careful consideration of requirements for both QoS and TCO.

In this section, we will explore these limitations and challenges before describing a number of methods for overcoming them.

Medium limitations:
Interference and self-interference

The wireless spectrum is subject to national regulation and divided into application-specific bands, licensed bands, and license-free bands. For IoT applications based on low-cost hardware the business case usually does not support the use of a licensed spectrum. Hence, to maintain a low TCO many IoT applications currently use a license-free spectrum. This is also the case for many smart metering systems.

According to Gartner, a typical family home could contain more than 500 smart devices by 2022.

Source: *http://www.gartner.com/newsroom/id/2839717*

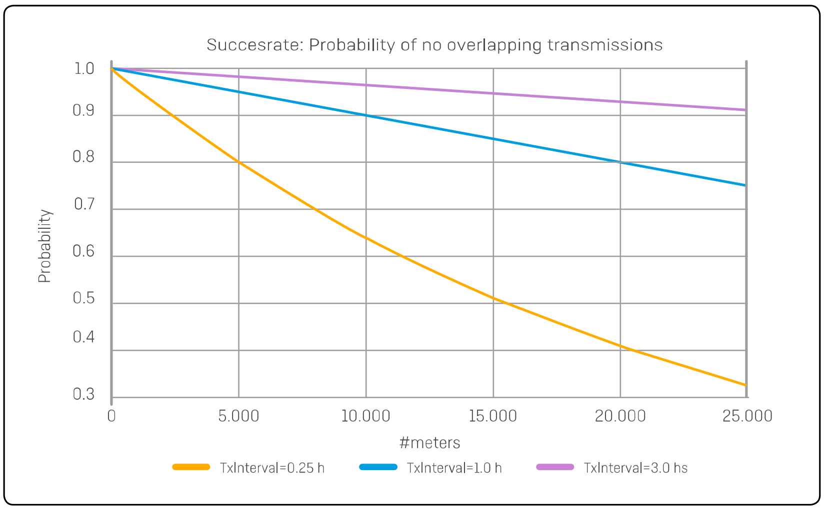
In coming years, numerous IoT applications are expected to emerge. According to recent market analysis, every residential household will contain up to 500 smart devices and sensors by 2022, adding up to tens of billions of devices connected to the internet.

As mentioned previously in relation to 5G, one of the major challenges for future wireless technology is massive access, regardless of whether a licensed or license-free spectrum is used. The sheer amount of devices within the same spectrum will be a source of interference.

One challenge is the multitude of applications; another is the number of devices within the same application. The transmissions from two or more devices may collide, i.e. overlap in time, causing heavy distortion of all involved transmissions, unless each transmission is centrally coordinated and carefully scheduled. Such coordination requires two-way communication. Having the receiver turned on would increase power consumption in the device. Hence, smart metering applications are often limited to uplink, from meter to concentrator, to conserve power. The meters, therefore, transmit their data packets in a somewhat periodic fashion.

The plot below shows how the probability of non-overlapping transmissions decreases as the meter population in the environment increases.

Access Limitations of the Wireless Medium



For simplicity, each transmission is assumed to have a 20ms duration in this example.

Environmental challenges: Mobility and locations

Another challenge is the propagation of wireless radio signals. The development of theoretical wireless propagation models originates from cellular technology or WiFi, where devices are mobile. The wireless channel is random by nature, and due to multipath propagation, the signal quality can vary significantly between positions separated by as little as a wavelength (for a 900MHz signal that is approximately 33cm).

When mobile devices move around they are likely to experience many positions with good signal quality (and many with bad), but on average they will have reasonable conditions to perform their data communication. However, the devices for many sensor applications, especially smart metering, are static installations and do not benefit from mobility. This means that if signal conditions are poor for a smart meter they are likely to stay poor.

Additionally, meters are often installed in what is referred to as deep indoor locations, i.e. in sculleries, basements or in concrete pits sealed with a cast iron lid. This means that the radio signal experiences severe attenuation even before it is 'outside'.

Also, existing theoretical propagation models focus on indoor-to-indoor or outdoor-to-outdoor propagation due to their origins within WiFi/cellular. However, for smart metering, and many IoT applications in general, indoor-to-outdoor propagation is highly relevant.

Propagation models like the one presented in the European Commision's report Digital mobile radio towards future generation system [3] therefore seek to account for the building penetration loss. Most recently this model has been applied in the work on preparing future cellular communication [4]. The model matches our own empirical investigations showing that building penetration losses between 20-30dB are common for the smart metering case. This means that only 1/1000 to 1/100 of the signal strength radiated from the meter actually reaches the outdoor environment.

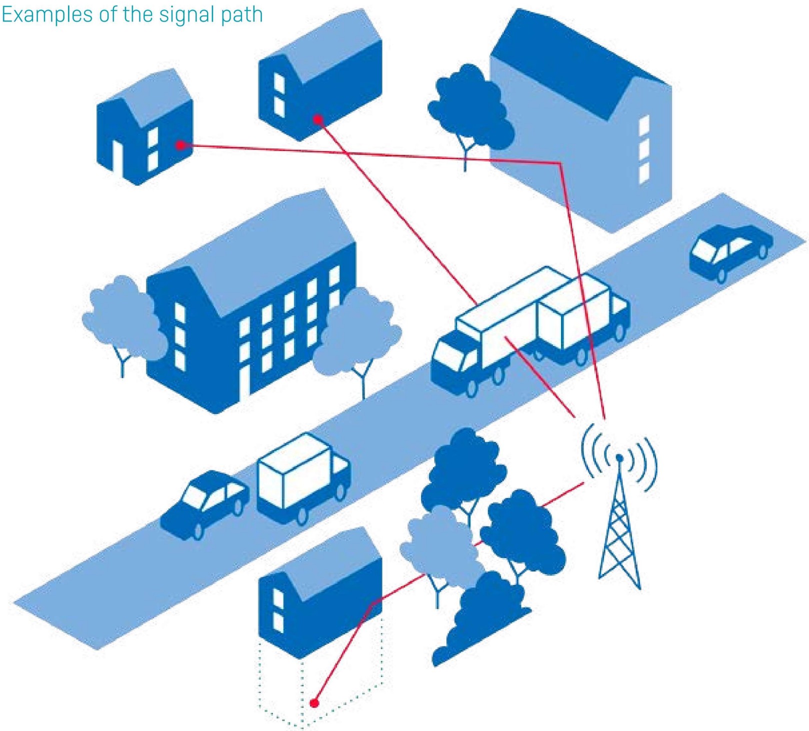
Once outdoor there is a multitude of factors that influence the signal in its path, such as other buildings, traffic and vegetation, all of which further attenuate the signal from the meter and makes it increasingly difficult to achieve reliable and robust communication between meters and concentrator.

It is important to note that no two environments are the same and they will thus affect the radio frequency (RF) propagation differently.

When designing the infrastructure for a given site, a detailed radio planning is required to ensure that the resulting coverage can meet the desired level of QoS.

Moreover, with TCO as the main competitive parameter, little margin is left for unforeseen propagation aspects. Luckily, there are several ways to increase the reliability and robustness of a system. We will take a closer look at them in the following section.

Examples of the signal path



Improving the reliability of smart meter data

When designing to meet the need for reliable communication and massive access in future wireless infrastructures for smart metering systems, there is not one right answer. Each method must be assessed.

There are various ways to increase the reliability of a system, each of which represents a trade-off between desired features and undesired consequences. In this section, we will outline the advantages and disadvantages of four common methods.

Method 1: Feedback

With two-way communication, the concentrator would be able to request additional data when needed. This allows for optimisation of the packet length of the periodic transmissions. Moreover, the concentrator would be able to acknowledge the data transmission from the meter. For meters located in good channel conditions, this would help reduce the transmissions necessary to meet a certain QoS, e.g. minimum one data sample per hour.

Less transmission mean less power consumed, even though some of that power is needed to receive concentrator transmissions instead. Also on the positive side, the meter will occupy the wireless medium less time, which may improve channel conditions for other meters in the system.

Realising receiver capabilities in the meter poses a challenge. Due to the physical dimensions of the meter and limited processing power, the receive sensitivity will be poor resulting in highly asymmetric uplink and downlink channels. This can to some extent be mitigated by letting the concentrator transmit with high power, but this option is usually limited by local regulations.

Two-way communication would, however, provide advantageous flexibility and allow transmission parameters to be reconfigured. In this way, the transmission scheme used by meters with good channel conditions could be optimised to minimise the use of the wireless medium, giving meters with poor conditions room to use more resources.

Method 2: Forward Error Correction (FEC)

FEC refers to the method where redundant data is transmitted to the receiver along with the meter data in order to increase the probability that the packet can be decoded correctly without two-way exchange of additional information.

This approach is opportunistic and offers no guarantee that the packet can be decoded correctly. The added redundancy increases the robustness of the system at the price of increased transmission time resulting in higher power consumption and decreased medium capacity.

As an example, consider the graph on page 9, which shows the probability of avoiding collisions. By employing FEC, a system will be able to cope with partially overlapping transmissions, which in effect will improve reception conditions. This corresponds to the plots in the above-mentioned graph being shifted horizontally upwards.

FEC is a well-known approach that has been used in wireless technologies for years. One example is the 3G cellular network first deployed in 2001. There are multiple algorithms for creating the redundancy, and it is possible to add it on several levels in the protocol stack.

Link-level redundancy

On the link level the method consists of making the redundancy packet specific. This means that once the receiver detects the packet, the probability of decoding the packet successfully is increased.

This approach increases the length of each individual packet but maintains a low latency in the sense that if the received packet can be decoded, its payload can be extracted and passed to the metering application immediately.

Packet-level redundancy

Another option is to introduce packet-level redundancy where complete packets of random data are added to a given set of packets. This approach protects against packet losses, as it does not require that all packets are detected. The undetected (i.e. lost) packets can be regenerated from the set of received packets, comprised of both data packets and redundant packets.

This is an advantage compared to link-level redundancy but the drawback is that it adds latency to the reception because the decoding/regeneration of a packet may depend on the reception of the remaining part of the packet set.

These two methods for FEC represent a trade-off between latency and data completeness, and whether to use one or the other, or a combination, depends on the desired QoS.

Method 3: Spread spectrum vs. narrowband operation

This method literally spreads the transmission across more resources and thereby makes it less susceptible to powerful interferers.

The spreading can be in frequency or in time, occupying either more bandwidth or requiring longer transmission times. The de-spread operation performed at the receiver will de-spread the wanted signal and spread any unwanted signals, which then improves the resulting Signal-to-Interference Ratio (SIR).

Narrowband operation can be considered the opposite of spread spectrum. When narrowing the band, it is possible to achieve a better Signal-to-Noise Ratio (SNR), as the noise level decreases. The narrow bandwidth also means that the maximum data rate is low, and so the payload must be decreased unless an increased power consumption from longer transmission times can be accepted.

Moreover, when the channel is narrow the receiver becomes more sensitive to frequency drift in the transmission. That means stricter requirements for component precision in the transmitter, something that potentially increases the cost.

When considering narrow band operation, the question whether to target licensed or license-free spectrum usually arises. In licensed spectrum, the operation is less restricted compared to license free spectrum, and the communication will experience less interference.

Method 4: Diversity

This is the discipline of creating multiple independent communication channels and the motivation for this is twofold, namely both massive access and reliability. With multiple independent channels, the probability of at least one having good channel conditions is higher compared to just having a single channel.

Moreover, with each meter cycling through multiple independent channels used in a random fashion, the number of potential colliding meter transmissions is effectively divided by the number of utilised channels.

In the next section, we will describe some of the ways to achieve multiple independent channels.

Antenna Diversity: If a concentrator has multiple antennas connected covering the same area, transmissions are likely to be received by all antennas. Due to the randomness in the wireless channel, each received copy of the packet will be distorted differently.

Hence, by combining these copies the resulting packet will have better characteristics than any of the individual copies. That increases the probability of decoding the packet. However, this diversity gain comes at the price of increased processing requirements for the concentrator.

Spatial Diversity: In contrast to antenna diversity, where multiple antennas cover the same areas, they can also cover separate areas and in this way divide the intended area (or device population) into smaller separate parts.

This may be a necessity in order to cover the intended area. But this approach can also be used actively to limit the number of unique packets received per antenna, and thereby reduce the level of self-interference from the meters in the field. In this way, the total number of decodable packets can be increased. However, this requires that the concentrator has the processing power to keep up.

Frequency Diversity: The multiple channels can also refer to separate frequency bands. The main drawback of this approach is the increased total bandwidth occupied by the system, which may not be feasible due to local regulations.

Technology Diversity: Having the option of communicating through multiple independent technologies enables a fall-back technology in case of poor channel conditions using the primary technology. The fall-back technology can very well have several limitations compared to the primary technology, but the reliability of the system is increased even if only a reduced dataset can be delivered by the fall-back technology.

The need for a dedicated smart metering infrastructure

In the end, every design is a trade-off with the aim of fulfilling the list of functionality requirements, which – from a technological perspective – can be opposing.

In recent years, several takes on the ideal IoT infrastructure have emerged, and when investigated in detail they all make use of one or more of the methods, we have described. The main strength of these infrastructures is the fact that they target the entire range of IoT applications as a whole. However, their broad focus is also their main weakness, as none of them is tailored to the specific requirements of the smart metering application.

That is why at Kamstrup, our aim is to provide leading technology for intelligent metering solutions tailored to the needs of the utilities. In this pursuit, the synergy created by a high degree of customer engagement and our in-house technological expertise plays an integral role and ensures that Kamstrup will continue to offer a dedicated smart metering infrastructure as part of our complete solutions for intelligent metering.

References

1. METIS, "Deliverable D8.4: METIS final project report," 2015. [Online]. Available: *https://www.metis2020.com/wp-content/uploads/deliverables/METIS_D8.4_v1.pdf.* [Accessed: 25-Nov-2015].
2. SWAN, "Global Utility Survey," 2014. [Online]. Available: *http://www.swan-forum.com/research.html*. [Accessed: 25-Nov-2015].
3. EuropeanCommision, COST Action 231 : *Digital mobile radio towards future generation systems* - Final report, no. May. 1999.
4. 3GPP, "TR 45.820: Cellular system support for ultra-low complexity and low throughput Internet of Things (CIoT)," 2015. [Online]. Available: *http://www.3gpp.org/ftp/Specs/archive/45_series/45.820/45820-d10.zip*. [Accessed: 30-Mar-2016].

Think forward

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