An Analysis of How to Deploy Low Power WAN IoT Using HFC and Fiber Network Infrastructure

A Technical Paper prepared for SCTE•ISBE by

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Introduction

In the last few years the telecommunications world has been focused on developing and deploying specific, viable IoT infrastructure as well as IoT-based business and use cases. However, most of the deployments are done in an OTT (Over-The-Top) manner over existing internet connections. This is in large part due to the network agnostic nature of many consumer IoT applications. IoT applications directly connect to their IoT providers through open internet connections, giving multiple subriber operators (MSOs) the traffic load, but cutting them out of any control of the quality of the service and also its revenues.

This paper analyzes the main alternatives of Low Power WAN (LPWAN) IoT native protocols such as LoRaWAN running over unlicensed spectrum compared to mobile based protocols such as LTE-M and NB-IOT using a typical MSO infrastructure as their support.

A detailed analysis of RF footprint for both alternatives is presented by using the existing infrastructure of the MSOs to support physical mounting, powering and network backhauling by either using in-home or out-of-home alternatives. This analysis focuses on the positioning of LoRaWAN access points in key positions of the hybrid fiber coax (HFC)/fiber network in order to effectively serve remote sensors in different types of scenarios of device densities, such as dense urban and suburban.

A backhauling analysis is presented showing the key elements to properly support the most important key performance indicators (KPIs) of IoT networks such as packet loss, latency and bandwidth over DOCSIS® transport.

Lastly a security and network transport layer model is presented in order to properly support thousands of remote access points/small cells without the necessity of dedicated managed transport networks. The use of internet security (IPSEC) protocol is analyzed together with the requirements for the tunnel termination requirements for supporting the mentioned topology.

The resulting conclusions will allow the cable operators to better understand how the different LP-WAN protocols behave at the RF level in certain configurations that are well aligned and resource efficient with current HFC-fiber infrastructure deployments in MSOs. This understanding may help MSOs better plan for LP-WAN network deployments.

Content

1. IoT background

The term "Internet of Things" (Internet of Things or IoT) was first used by Kevin Ashton in 1999 in the context of a presentation on how to improve the efficiency of a company's supply chain systems of provision of goods through the use of radiofrequency markers (RFID) instead of bar codes and how to achieve an automated data collection through the use of a network and mainly the elimination of the human factor in said data collection (Ashton, 2009). This is particularly important given that the term "Internet of Things" brings with it the concept that "things start to use the network in such a way that people do not need to" as Neil Gershenfeld (1999) mentioned and relates the automation of the communication of things, now tied to the growth of the internet as a network of global interconnection (Gershenfeld, 1999).

In 2012, one of the broadest definitions of the Internet of Things was made by the International Telecommunications Union (ITU). Which defines it as "the global infrastructure for the information society that facilitates the provision of advanced services through the interconnection of objects (physical and virtual) thanks to the interoperability of present and future information and communication technologies" (ITU, 2012). Likewise, each of these things or objects is an object of the physical world (physical objects) or the world of information (virtual objects) that can be identified and integrated into communication networks.
A very important factor also defined by the ITU is the ubiquity of communication. As seen in Figure 1, the Internet of Things adds a new dimension, that of communication between objects, and not just between computers or people (ITU, 2012).

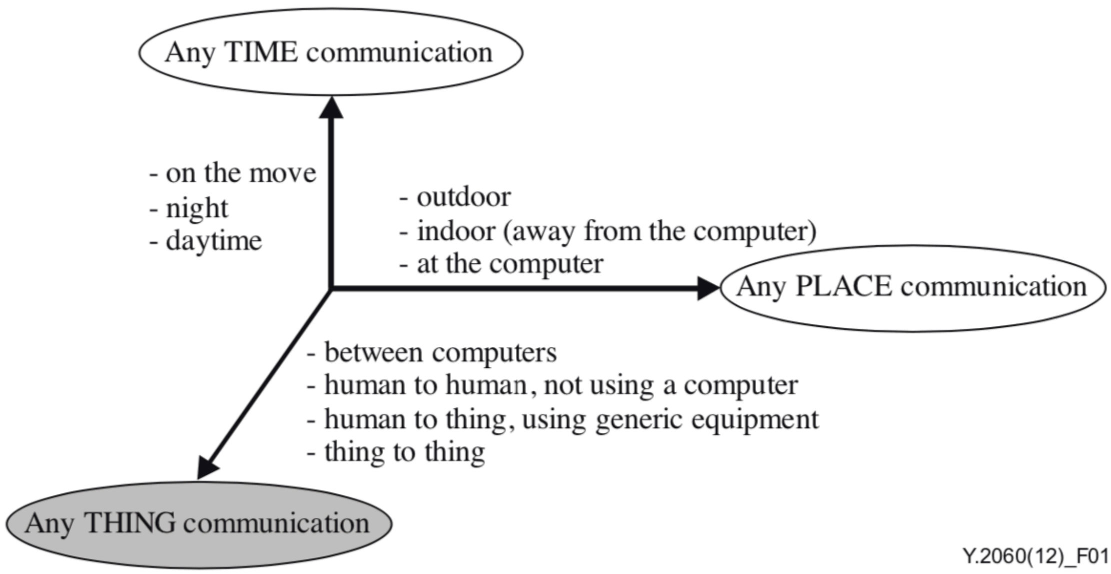


Figure 1 - The dimensions of communications in IoT. Retrieved from (ITU, 2012)

A goal of vital importance for the development of the internet of things was the creation of intelligent environments and spaces with "own life" things (see eg smart transport, products, cities, rural areas, health) (Smith, 2012). Said intelligent spaces or environments require a set of technologies functioning in a coordinated manner, which ranges from: the sensors, going through local processing, the interconnection of the sensors, and reaching the use of mass data processing in the cloud, as shown in Figure 2.

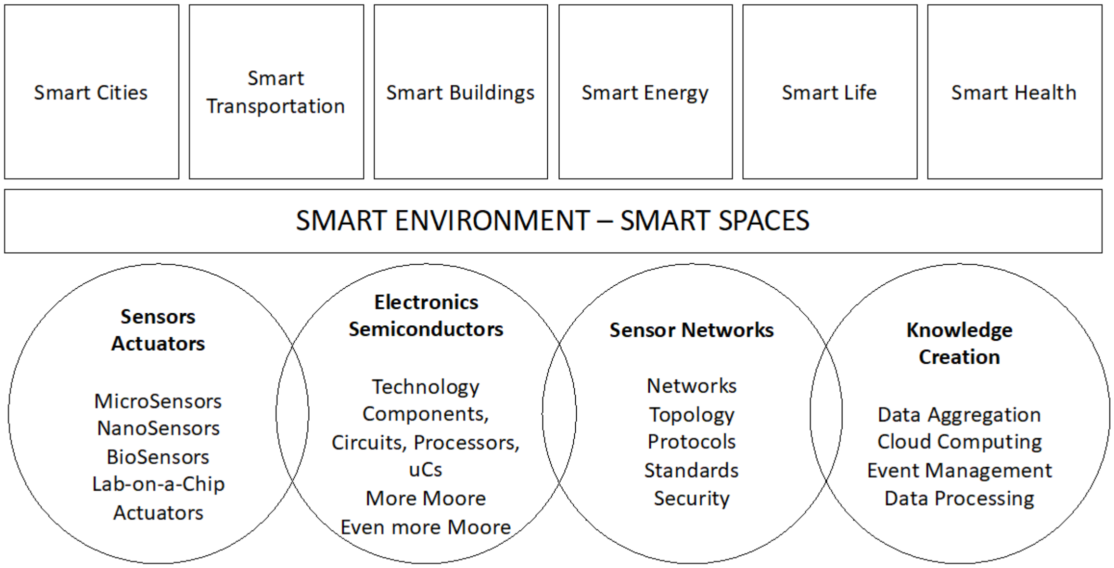


Figure 2 - Creation of environments and intelligent spaces. Adapted from (Smith, 2012)

A list of different Internet of Things applications based on different sensors and in different market segments is shown in Table 1.The list includes 8 different verticals in which the most striking scenarios are mentioned (Libelium, 2018).

To exchange data between applications, devices and things, there are several communication standards such as Bluetooth, WiFi and several mobile standards based on GSM (2G / 3G / 4G). In general these standards have achieved, with technological advances, significant increases in transmission of data rates and therefore the ability to transmit images or videos in real time. Most of the IoT use cases mentioned above do not require very high data transmission rates, but they do require very low energy consumption, since the sensors in general are located in remote areas with access challenges and very limited space for the placement of batteries.

2. Low Power Area Networks (LPWAN)

As a result, the goal of Low Power Wide Area Networks (LPWAN) has become a central issue in the IoT. LPWAN is a broad term where there isa variety of technologies used to connect sensors and controllers to the Internet without the use of WiFi or traditional cellular networks. Two primary standards have emerged for LPWAN networks: those based on cell phones, for example, NB-IoT or LTE-M; and those developed natively for IoT use cases such as LoRaWAN and SigFox. The predominant design considerations are low power consumption (up to more than 10 years of autonomy), strong penetration, the connection of a large number of sensors and very low bandwidth devices (Hassan, 2018).

From 2016 through at least 2022, IoT devices are expected to increase in number at a compound annual rate of 21 percent, driven by the new use cases mentioned above (Ericsson, 2016),therefore the need for spectrum will be marked to serve nearly 29 billion devices of which at least 2100 million will be of the LPWAN type, Figure 3.

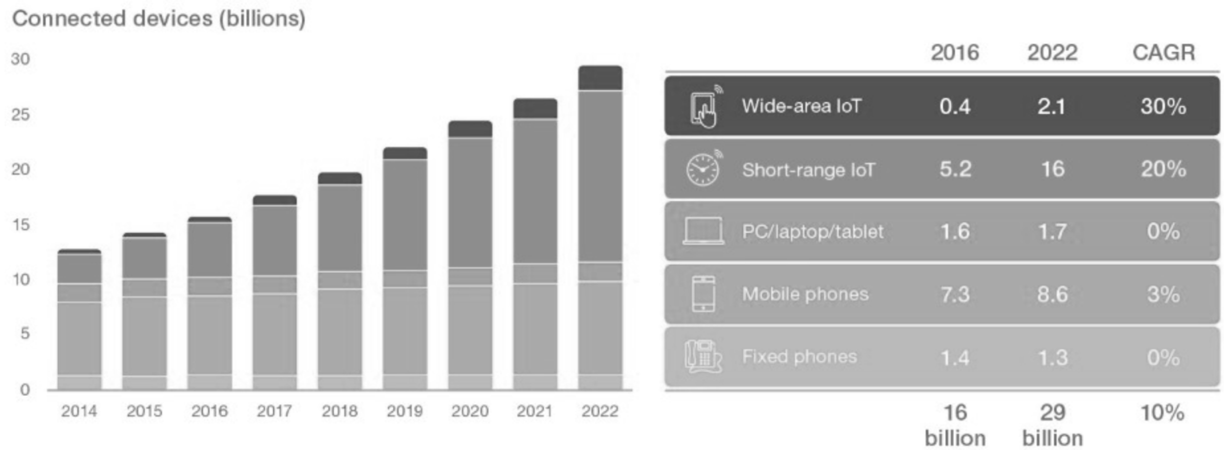


Figure 3 - Projection of connected Devices. Retrieved from (Ericsson, 2016)

3. LoRaWAN

Compared with other modulation techniques, the spread spectrum technique used in LoRaWAN ensures a greater range of links, as well as better immunity to interference. LoRaWAN uses a 125 kHz to transmit the signal but also allows the use of scalable bandwidth between 125 kHz, 250 kHz or 500 kHz (Reynders, Meert, & Pollin, 2016). The use of a wider band makes LoRaWAN resistant to noise, Doppler effects, long-term variations of oscillators and fading. However, the use of a narrowband signal in a much wider band makes the spectrum less efficiently used, unless a generation of perfectly orthogonal signals is achieved between the different transmitters (Noreen, Bounceur, & Clavier, 2017).

The transmitter generates signals by varying its frequency over time and keeping the phase constant between adjacent symbols. The signal transmitted is a signal similar to noise that is resistant to multipath fading and Doppler, and is robust against interference. The receiver can decode even a very attenuated signal of 20 dB below the noise level (Semtech, 2013).
The error correction technique used in LoRaWAN to further increase the sensitivity of the receiver is the FEC (Forward Error Correction) type, particularly through the use of a Hamming code of adjustable length (Europe Patent No. 13154071.8, 2013). The code rate (CR) defines the amount of FEC and LoRaWAN offers CR values between 1 and 4. LoRaWAN uses code rates, Coding Rate = 4 / (4 + CR) or 4/5, 4/6, 4/7 and 4/8. If the code rate is denoted as k = n, where k represents useful information and the coder generates n number of output bits, then n - k will be the redundant bits. Redundancy allows the receiver to detect and correct errors in the message at the cost of decreasing the effective data rate as evidenced in Table 1.

Table 1 - Code Rates for LoRaWAN. Adapted from (Noreen, Bounceur, & Clavier, 2017)

CR	1	2	3	4
Coding Rate	4/5	4/6	4/7	4/8
Efficiency	0.8	0.666	0.571	0.5

In LoRaWAN you can choose a variable spreading factor (SF) as a function of the received signal-to-noise ratio (SNR). This spreading factor adapts the length of the symbol and at the same timealso specifies the number of bits per symbol. Therefore, changing the spreading factor gives a variable bit rate between 366 bps for the highest propagation factor (SF = 12) and 48 kbps for the lowest propagation factor (SF = 6) as shown in Equation 1

$$R_b = \frac{BW}{2^{SF}} * SF \text{ [bits/seg]}$$

Equation 1. LoRaWAN bit rate

With Coding

$$R_b = \frac{\frac{4}{4+CR}}{\frac{2^{SF}}{BW}} * SF \text{ [bits/seg]}$$

Equation 2. LoRaWAN bit rate with coding

Although the choice of a higher spreading factor increases the bit rate, higher spreading factor reduces the maximum range of the transmission and the same occurs in the opposite direction. Each symbol is scattered with scatter code of 2^{SF} chips in length. In the transmitter, the scatter code is subdivided into codes of length 2^{SF} / SF. Then, each bit of the symbol is scattered using the sub code. Therefore, 2^{SF} chips are needed to propagate a symbol. This same spreading code is also known in the receiver. The replacement of a symbol by multiple information chips means that the spreading factor has a direct influence on the effective data rate (Noreen, Bounceur, & Clavier, 2017), as shown in Figure 4.

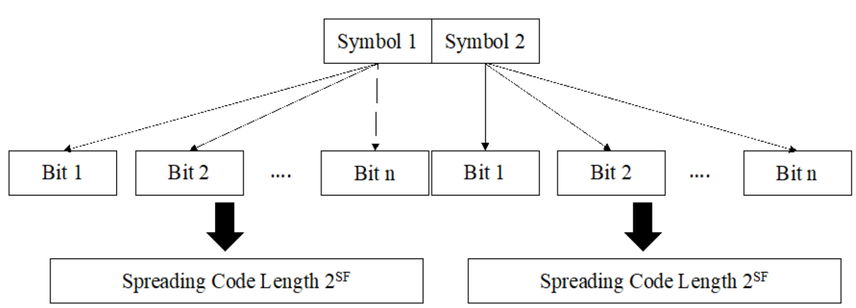


Figure 4 - Spreading of Symbols in LoRaWAN

The choice of a longer length of spread code improves the transmission distance, but at the cost of a lower bit rate given by the increase in time in the air. This follows from the application of the Shannon-Hartley theorem that establishes the maximum possible information rate for a channel with noise at a given bandwidth as seen in Equation 3 (Proakis, 2000)

$$C = B * log_2\left(1 + \frac{S}{N}\right) \text{ [bits/seg]}$$

Equation 3. Shannon's theorem

Where:
C = Channel capacity
B = Channel bandwidth
S = Average signal power in the receiver
N = Average noise power in the receiver
S / N = Signal to noise ratio in the receiver

If the logarithmic ratio of base 2 to natural base is converted and also assumed that for a spread spectrum application the small signal to noise ratio and the signal power will be much lower than the noise, then S / N << 1 and Equation 2 can be rewritten as Equation 4.

$$\frac{C}{B} = 1.43 * \frac{S}{N}$$

Equation 4. Simplified Shannon's Theorem for Spread Spectrum

Therefore, it follows that in order to transmit error-free information to a given signal-to-noise ratio, it is only necessary to increase the bandwidth of the channel to transmit more information. (Semtech Corporation, 2015)

Now, given that the floor noise also called Johnson-Nyquist thermal noise, is determined by the channel bandwidth according to Equation 5 (Sam Lee & Miller, 1998)

$$N_{Floor} = 10 * log_{10}(k_B * T * B * 1000)\ [dBm]$$

Equation 5. Johnson-Nyquist noise

Where:
k_B = Boltzman constant ($1.38 * 10^{-13}$ m^2kg/s^2 K)
T = Temperature [K]
B = Channel Bandwidth [Hz]
1000 = Conversion of watt to milli watt

Assuming T = 293 K and simplifying $N_{Floor} = -174 + 10 * \log_{10}(B)$ dBm, Equation 6 is obtained, where it is shown that the noise floor depends on the bandwidth of the channel used.

$$N_{Floor} = -174 + 10 * log_{10}(B)\ [dBm]$$

Equation 6. Johnson-Nyquist noise at room temperature

If you want to obtain the minimum detectable signal or sensitivity in a receiver, you should consider this noise figure, and the minimum signal to noise ratio required for the modulation to be used as shown in Equation 7.

$$S = -174 + 10 * log_{10}(B) + NF + SNR \; [dBm]$$

Equation 7. Sensitivity of a radio receiver

3.1. Link Budget

If you wish to establish the link budget, this is determined by Equation 7

$$Link\ Budget \; = \; Minimum\ Detectable\ Signal - \; Maximum\ Transmit\ Power \; [db]$$

Equation 7. Link calculation

The maximum range is given by the link budget considering the signal attenuation in free space (FSPL) according to Equation 8. (Sam Lee & Miller, 1998).

$$FSPL = 20 * log_{10}(d) + 20 * log_{10}(f) + 20 * log_{10}\left(\frac{4\pi}{c}\right) \; [dB]$$

Equation 8. Attenuation of free space

Considering f=900 MHz

$$FSPL \; = 20 * log_{10}(d) + 31.53 \; [dB]$$

Equation 9. Attenuation of free space at 900 Mhz.

The LoRaWAN protocol establishes a packet format that can be seen in Figure 5, which shows that the higher the error correction rate (CR), the longer the packet will be for a given payload.

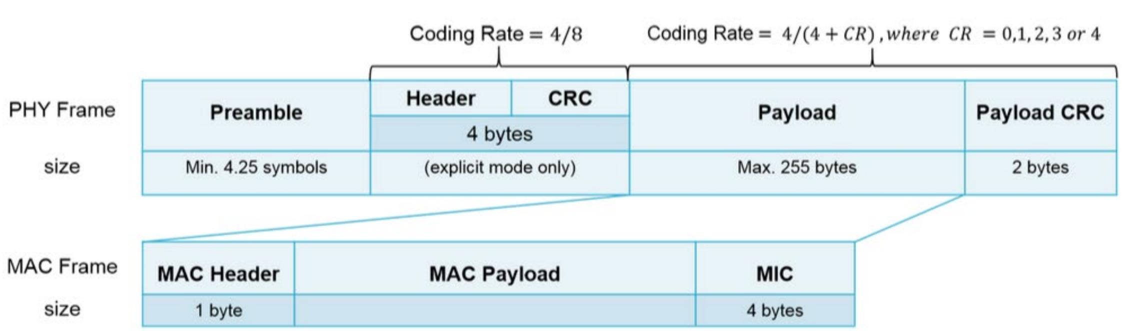


Figure 5 - LoRaWAN package structure. Retrieved from (Semtech, 2013)

The air time a LoRaWAN package is given by Equation 10.

$$T_{Packet} = T_{Preamble} + T_{Payload}\ [seg]$$

Equation 10. LoRaWAN Air Time

The preamble time LoRaWAN package is given by Equation 11.

$$T_{Preamble} = (n_{Preamble} + 4.25) * T_s\ [seg]$$

Equation 11. LoRaWAN Preamble Time

The time of a LoRaWAN symbol is given by Equation 12 and is related to the symbol rate.

$$T_s = \frac{1}{R_s}\ [seg]$$

Equation 12. LoRaWAN Symbol Time

The LoRaWAN symbol rate is given by Equation 13 and is related to the channel bandwidth (BW) and the spreading factor (SF).

$$R_s = \frac{BW}{2^{SF}}$$

Equation 13. LoRaWAN Symbol Rate

The total time of the LoRaWAN payload is given by Equation 14 and is related to the channel bandwidth (BW) and the spreading factor (SF).

$$T_{Payload} = PL_{Symb} * T_s$$

Equation 14. LoRaWAN Payload Time

The total time of a LoRaWAN package is given by Equation 15 that derives from Equation 14, Equation 11, Equation 12 and Equation 13 and is related to the channel bandwidth (BW) and the spreading factor (SF).

$$T_{Packet} = (n_{Preamble} + 4.25 + PL_{Symb}) * \frac{2^{SF}}{BW}$$

Equation 15. LoRaWAN packet time

Considering the previous points, it can be summarized for a LoRaWAN system that the air time of a packet is multiplied exponentially for higher spreading factor values as shown in Table 2.

Table 2 - Spreading Factor vs Chip Length

SF	2^{SF}
6	64
7	128
8	256
9	512
10	1024
11	2048
12	4096

Using Table 3 the link budget is displayed for different spreading factors based on the gain of 2.5 dB for each factor step. For the elaboration of said use table a typical receiver noise figure of 6 dB, as specified in the manuals of the receiver and a maximum transmission power of 14 dBm, as specified for LoRaWAN 2.0. (Semtech, 2013)

Table 3 - Spreading Factor vs. Link Sensitivity and Budget

SF	chips/symbol	SNR Limit [dB]	Noise Figure [dB]	BW [Hz]	Sensitivity [dBm]	TX Power [dBm]	Link Budget [dB]
6	64	-5	6	125000	-122.03	14.00	-136.03
7	128	-7.5	6	125000	-124.53	14.00	-138.53
8	256	-10	6	125000	-127.03	14.00	-141.03
9	512	-12.5	6	125000	-129.53	14.00	-143.53
10	1024	-15	6	125000	-132.03	14.00	-146.03
11	2048	-17.5	6	125000	-134.53	14.00	-148.53
12	4096	-20	6	125000	-137.03	14.00	-151.03

Considering Equation 9, this puts the maximum theoretical reach of LoRaWAN for SF=12 at 900 Km. The current world record using standard equipment is 702 km (The Things Network, 2017).

In Table 4, it is clear, that the impact of using a larger spreading is significant on the total bitrate of the channel.

Table 4 - Channel Bitrate vs Channel Bandwidth, Spreading Factor and Coding Rate

		SF						
BW	500000	6	7	8	9	10	11	12
CR	0	46875	27344	15625	8789	4883	2686	1465
	1	37500	21875	12500	7031	3906	2148	1172
	2	31250	18229	10417	5859	3255	1790	977
	3	26786	15625	8929	5022	2790	1535	837
	4	23438	13672	7813	4395	2441	1343	732
BW	250000	6	7	8	9	10	11	12
CR	0	23438	13672	7813	4395	2441	1343	732
	1	18750	10938	6250	3516	1953	1074	586
	2	15625	9115	5208	2930	1628	895	488
	3	13393	7813	4464	2511	1395	767	419
	4	11719	6836	3906	2197	1221	671	366
BW	125000	6	7	8	9	10	11	12
CR	0	11719	6836	3906	2197	1221	671	366
	1	9375	5469	3125	1758	977	537	293
	2	7813	4557	2604	1465	814	448	244
	3	6696	3906	2232	1256	698	384	209
	4	5859	3418	1953	1099	610	336	183

3.2. Effects of Aloha in LoRaWAN

The MAC of LoRaWAN is based on Pure ALOHA. If we define S as the average number of packets generated per interval; the traffic source λ consists of a high number of users who form an independent poisson source with an aggregate packet rate of X packets/s, the packet time width is supposedly fixed with a period of T seconds. It can be considered that each user generates packets infrequently. S can also be expressed as the channel throughput rate. A node delays the transmission of a previously collided packet with a random time. Therefore, the total traffic is not only new packets but repetition of retransmission of collided packets

$$S = \lambda T$$
$$G \geq S$$
$$G(n) = \lambda(n)T$$
$$S = G(n)P_{Suc} = \lambda(n)T * e^{-\lambda(n)2T}$$

Equation 15. LoRaWAN packet time

In Pure ALOHA, a successful transmission happens if the channel is free during the time period 2T (vulnerability period). The probability that there are no transmissions in the 2T period is

Psuc. The total channel traffic could be expressed as presented in Equation 15. With these constraints, it is possible to show that the maximum channel throughput is 18% (Kleinrock, 1975) as shown in figure 5. (Polloneli, 2019)

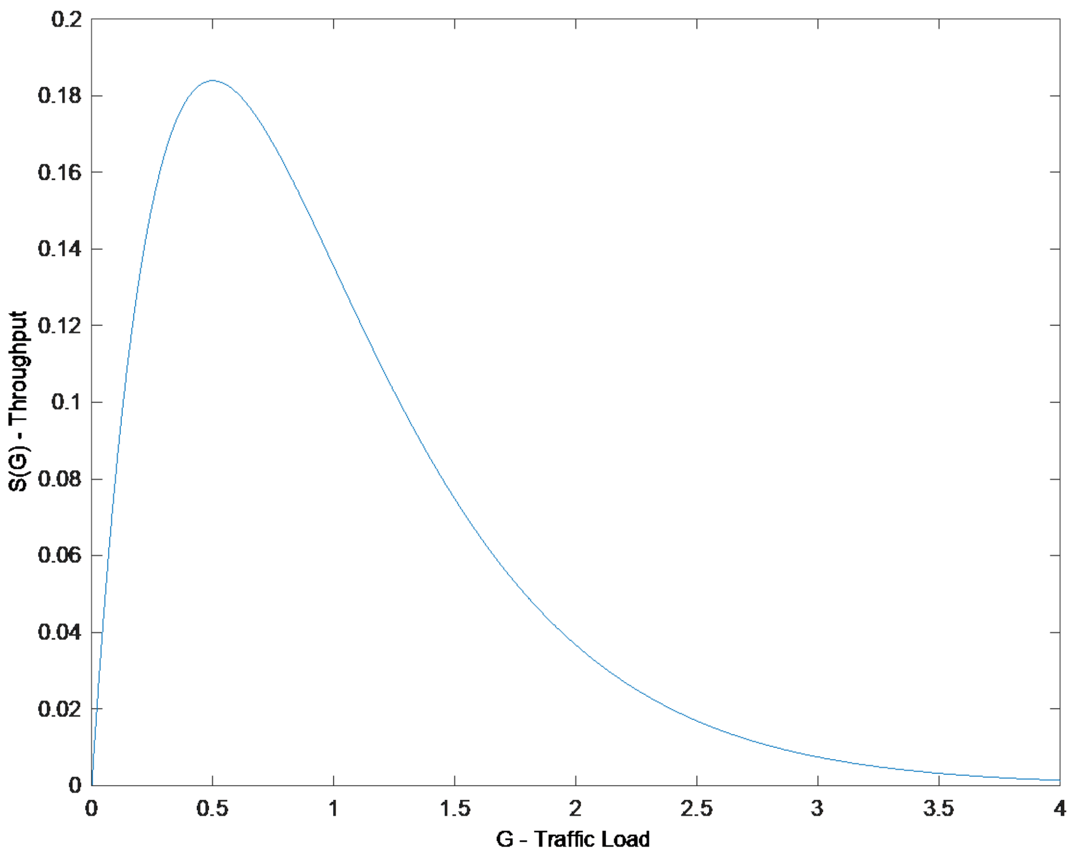


Figure 6 - Channel Thoughtput vs Channel Load for LoRaWAN

The total maximum adjusted bandwidth per channel considering Aloha MAC for 125 KHz Channels is shown in table 5.

Table 5. Channel Bitrate vs Spreading Factor and Coding Rate for Aloha MAC

0.18	125000	6	7	8	9	10	11	12
CR	0	2109	1230	703	396	220	121	66
	1	1688	984	563	316	176	97	53
	2	1406	820	469	264	146	81	44
	3	1205	703	402	226	126	69	38
	4	1055	615	352	198	110	60	33

Considering an 8 channel (125 KHz.) gateway, the total bandwidth is found in Table 6.

Table 6 - Total gateway Bitrate vs Spreading Factor and Coding Rate for Aloha MAC in an 8-channel gateway.

8	125000	6	7	8	9	10	11	12
CR	0	16875	9844	5625	3164	1758	967	527
	1	13500	7875	4500	2531	1406	773	422
	2	11250	6563	3750	2109	1172	645	352
	3	9643	5625	3214	1808	1004	552	301
	4	8438	4922	2813	1582	879	483	264

3.3. Signal Propagation Models

There are a few propagation models for signals in the UHF frequency range, and the best known is the Okumura-Hata model. Hata's model gives the value of pathloss at given distance between a base station and a mobile user. It considers several factors such as frequency, antenna heights and others (Hata, 1980).

$$L_P = 69.55 + 26.26\log(f) - 13.82\log(h_B) - CH + [44.9 - 6.55\log(h_B)]\log(d)$$

For a medium small city

$$CH = (1.1\log(f) - 0.7)h_M - (1.56\log(f) - 0.8)$$

L_P = Path loss in urban areas. Unit: decibel (dB)
h_B = Height of base station above ground (meters)
h_M = Height of mobile station above ground (meters)
f = Transmit frequency (MHz)
CH = Antenna height correction factor
d = Distance from gateway to device (km)

This model works very well for most IoT applications however its accuracy is limited by a minimum base station height of 30m (98 feet). In this analysis, the base station will be on the fiber node location, which is typically between 8-12m (26 to 39 feet) in height, so this model is not directly applicable.

A more accurate model for low height antennas is described in (Vilardi, 2012) and better applies for the scenario studied in this paper. This model considers urban and suburban models as well as outdoor/indoor commercial concrete walls and residential wood frame and/or brick wall applications.

This model has been done on a 900 MHz band, so perfectly applies for this study.

$$L_P = 20\log(h_B) + 20\log(h_M) - 43.36\log(d) - A - B - C$$

L_P = Path loss in urban areas. Unit: decibel (dB)
h_B = Height of base station above ground (meters)
h_M = Height of mobile station above ground (meters)
d = Distance from gateway to device (m)
A = Constant – Area type - 24.3 dB in suburban and 29.3 dB in urban
B = Constant – Building Attenuation – 0 dB Outdoor, 17.7 dB for Commercial Building (concrete) and 5.4 dB for suburban house (wood and brick frame)
C = Constant – Shadowing Affect - 0 dB Outdoor, 9.3 dB for Commercial Building and 6.4 dB, for residential

3.4. Frequency Plan

The spectrum in the USA for LoRaWAN has 64 uplink channels available (125 kHz each) (channels 0-63) starting at 902.3 MHz which increment every 200 kHz up to 914.9 MHz
There are 8 overlapping uplink channels (500 kHz each) (channels 64-71) from 903 MHz which increment every 1.6 MHz up to 914.2 MHz.
For gateway to node communication, there are 8 downlink channels (500 kHz each) (channels 0-7) from 923.3 MHz which increment every 600 kHz up to 927.5 MHz.

Table 7 - Spectrum bands for LoRaWAN in the USA

Uplink sub-bands	**Frequency range (MHz)**	**Channels**
Sub-Band 1	902.3 - 903.7	0-7
Sub-Band 2	903.9 - 905.3	8-15
Sub-Band 3	905.5 - 906.9	16-23
Sub-Band 4	907.1 - 908.5	24-31
Sub-Band 5	908.7 - 910.1	32-39
Sub-Band 6	910.3 - 911.7	40-47
Sub-Band 7	911.9 - 913.3	48-55
Sub-Band 8	915.5 - 914.9	56-63
Downlink sub-bands	**Frequency range (MHz)**	**Channels**
Downlink sub-band	903 - 914.2	64-71

3.5. Scenario Modeling

A) Dense Urban with Concrete Buildings and Indoor sensors

For a typical LoRaWAN network with a gateway running on a Fiber node on the strand let's assume $h_B = 9m = 30\ ft$ and $h_M = 1.5m = 4\ ft$
Model boundary conditions

$$h_B = 9m$$

$$h_M = 1.5m$$
$$A = 29.3dB$$
$$B = 17.7dB$$
$$C = 9.3dB$$

$$L_P = 20\log(9) + 20\log(1.5) - 43.36\log(d) - 29.3 - 17.7 - 9.3$$

$$L_P = 19.08 + 3.52 - 43.36\log(d) - 29.3 - 17.7 - 9.3$$

$$L_P = -43.36\log(d) - 33.7$$

Plotting the pathloss as a function of the distance as in Figure 7, the thresholds for operation in the most resilient and faster spreading factors are marked, SF=12 (red) and SF=6 (green).

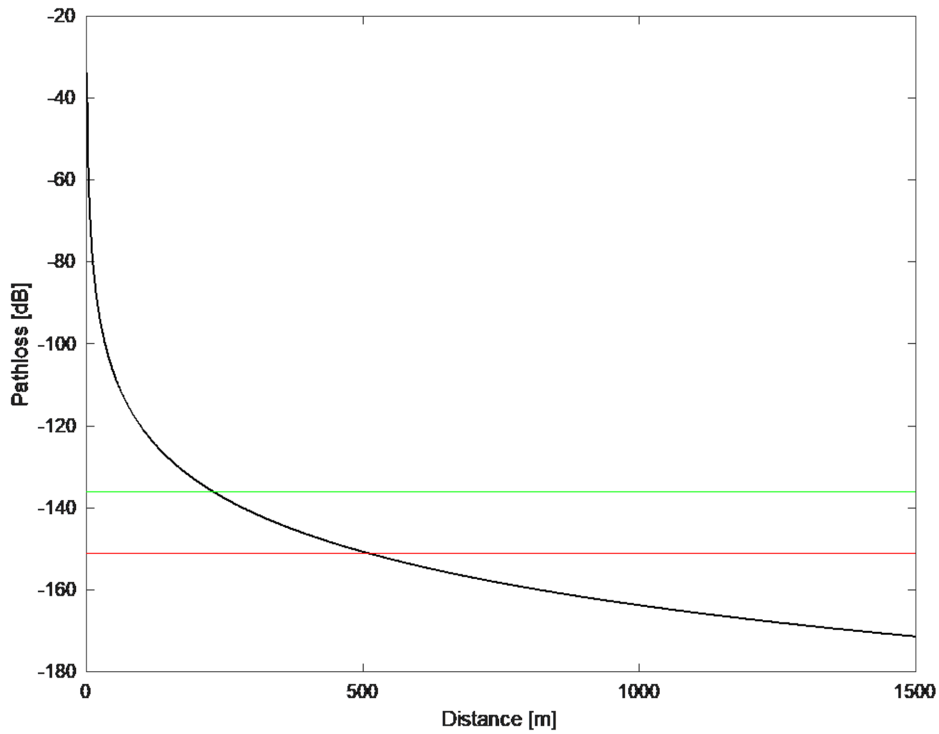


Figure 7 - Pathloss vs Distance for Dense Urban scenario

The maximum distance for different spreading factors can be calculated based on its link budget as show in table 4.

$$d = 10^{\left(\frac{L_B+33.7}{-43.36}\right)}$$

For SF=12, $L_B = -151.08$ dB

$$d = 10^{\left(\frac{-151.08+33.7}{-43.36}\right)}$$

$$d = 509.5m$$

For SF=6, $L_B = -136.03$ dB

$$d = 10^{\left(\frac{-136.03+33.7}{-43.36}\right)}$$

$$d = 229.1m$$

The conclusion is that in a dense urban scenario with concrete buildings a LoRaWAN network can operate with the least efficient transmission mode up to 509.5m (1671 feet) and the limit for the most efficient profile is 229.1m (751 feet).

B) Sparse Suburban with Houses and Indoor sensors

For a typical LoRaWAN network with a gateway running on a fiber node on the strand, assume $h_B = 9m = 30\ ft$ and $h_M = 1.5m = 4\ ft.$

Model boundary conditions

$$h_B = 9m$$
$$h_M = 1.5m$$
$$A = 24.3dB$$
$$B = 5.4dB$$
$$C = 6.4dB$$
$$L_P = 19.08 + 3.52 - 43.36\log(d) - 24.3 - 5.4 - 6.4$$

$$L_P = -43.36\log(d) - 13.5$$

Plotting the pathloss as a function of the distance as in Figure 8, the thresholds for operation in the most resilient and faster spreading factors are marked, SF=12 (red) and SF=6 (green).

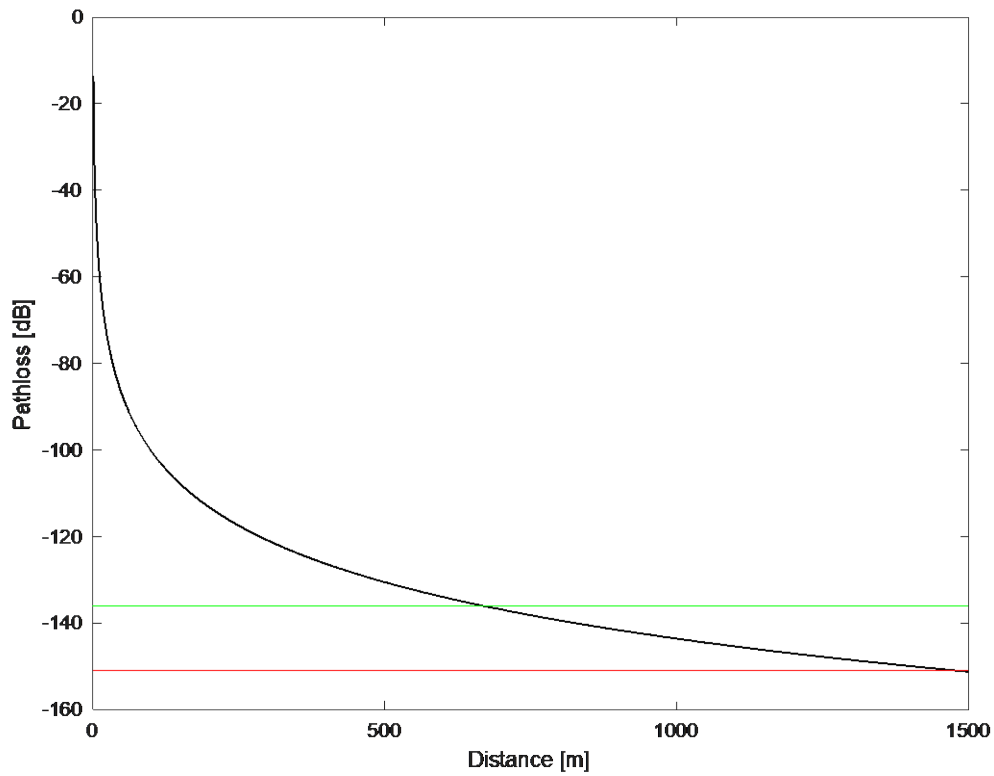


Figure 8 - Pathloss vs Distance for Sub-Urban scenario

$$d = 10^{\left(\frac{L_B + 13.5}{-43.36}\right)}$$

For SF=12, $L_B = -151.08$ dB

$$d = 10^{\left(\frac{-151.08 + 13.5}{-43.36}\right)}$$

$$d = 1489.25m$$

For SF=6, $L_B = -136.03$ dB

$$d = 10^{\left(\frac{-136.03 + 13.5}{-43.36}\right)}$$

$$d = 669.7m$$

The conclusion is in a dense urban scenario with concrete buildings a LoRaWAN network can operate with the least efficient transmission mode up to 1489.25m (0.89 miles) and the limit for the most efficient profile is 669.7m (0.42 miles).

4. HFC Networks

4.1. HFC Node + 0 Networks

HFC networks with 0 amplifiers in cascade typically have short coaxial cable runs that expand in average no more than 200 meters (600 feet) from the node location and even less than 150 meters in dense cities like the example in Figure 9.

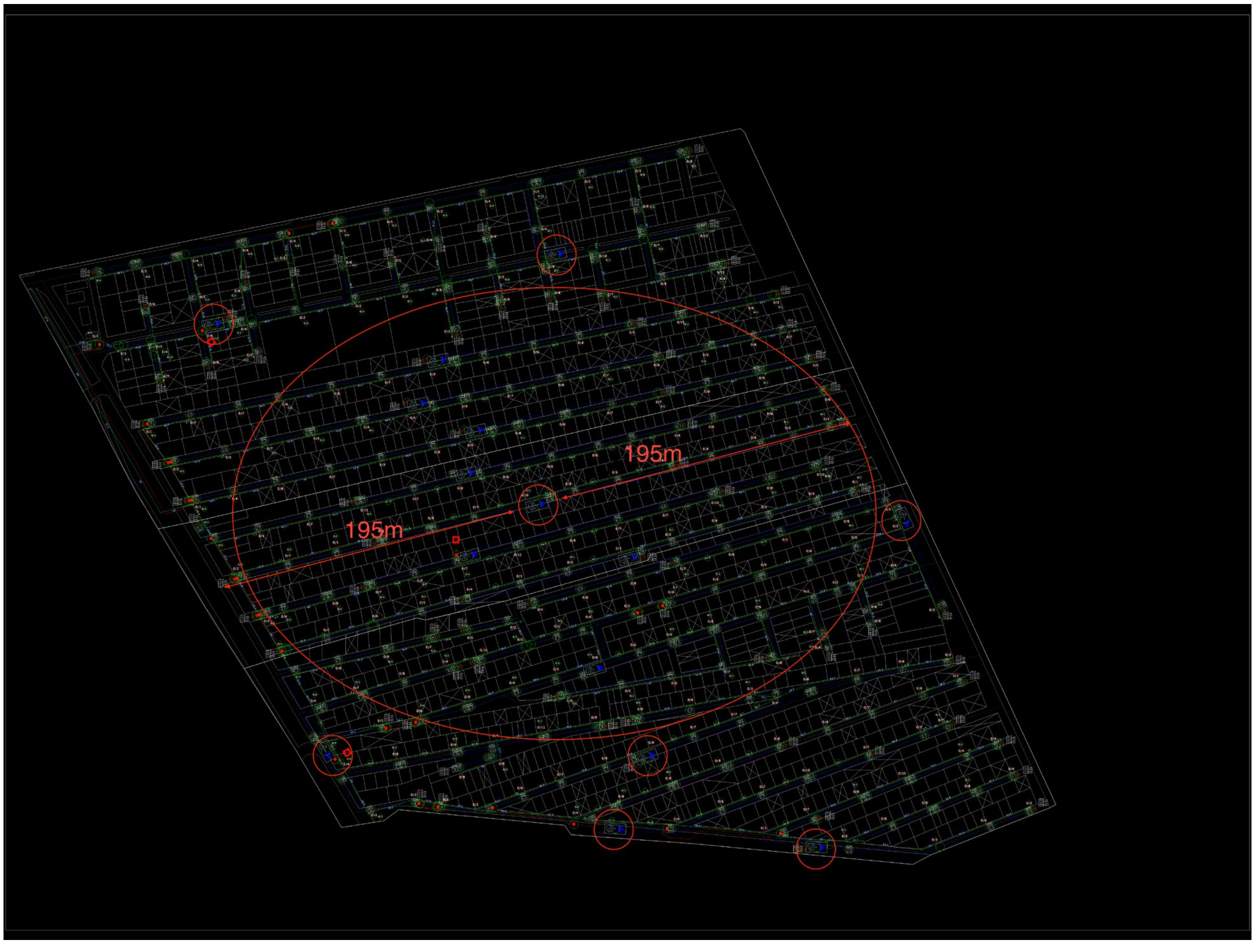


Figure 9 - Node+0 sample node distribution

That scenario is really aligned if the LoRaWAN gateway is collocated in the fiber node with the LoRaWAN configuration presented in section 3.3 where a maximum distance of 229 m (751 feet) is required to serve stations using maximum capacity SF=6.
In this scenario not all fiber nodes need to have a LoRa gateway because the distance exceeds signal reach.

4.2. HFC Node+1/2 Networks

HFC Networks with 1 amplifier in cascade typically have medium coaxial cable runs that expand in average 500 meters (1500 feet) from the node location in not so dense cities with houses as illustrated in Figure 10.

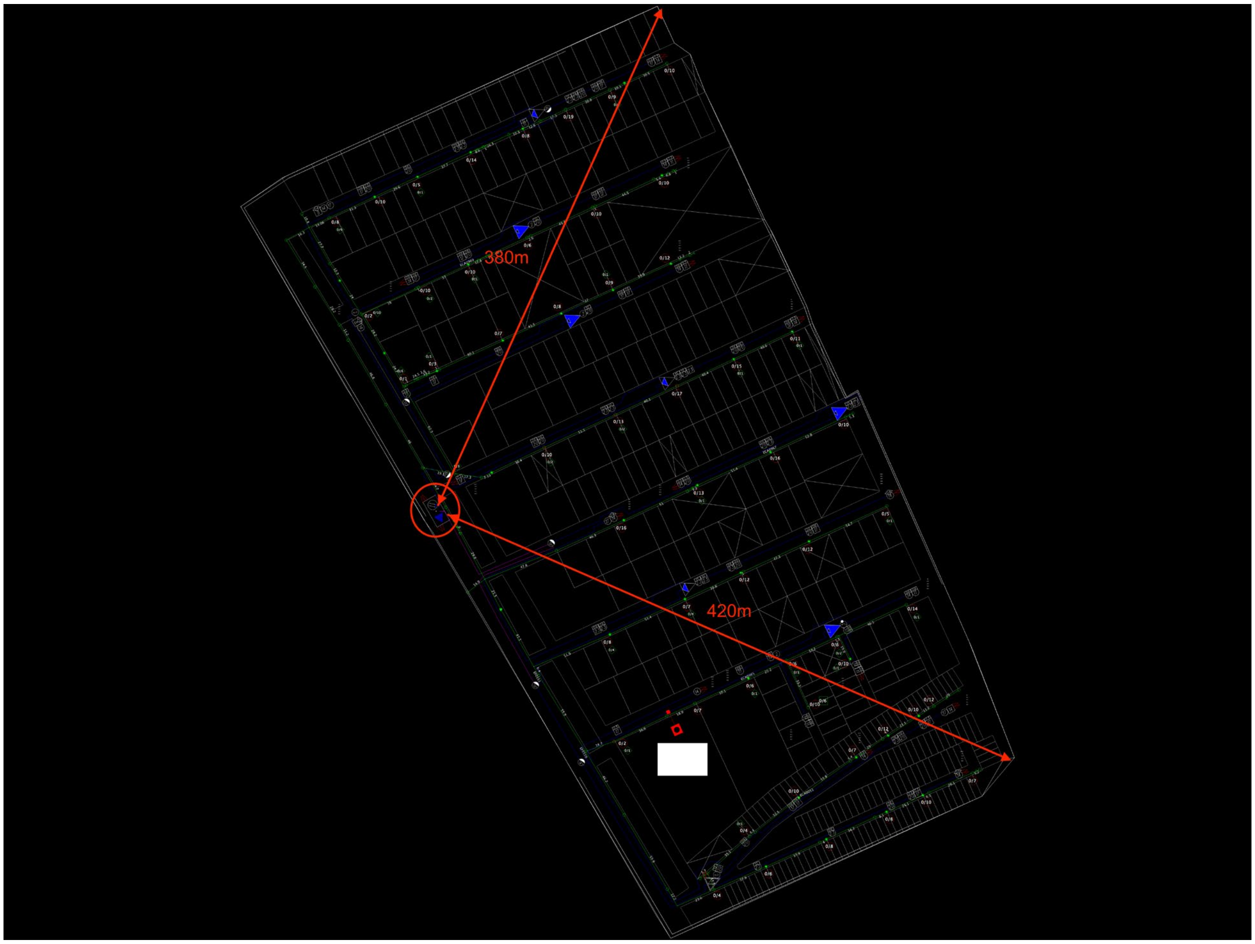


Figure 10 - Node+1/2 sample node distribution

This scenario is really aligned if the LoRaWAN gateway is collocated in the fiber node with the LoRaWAN configuration presented in section 3.4; where a maximum distance of 669 m (751 feet) is required to serve stations using maximum capacity SF=6.
In this scenario all fiber nodes need to have a LoRa gateway, as the distance is well aligned with the wireless reach.

5. Network Density and Throughput

Considering the different IoT applications, it is very important to be able to model the traffic patterns and device densities according to the area density. In this section we will consider public usage and some residential use cases where data traffic is not intensive. The device density per suburban and urban areas was taken from (Huang, 2011).

Table 8 Shows the average data rates and reporting periods for public applications.

Table 8 - Public Applications Communication Parameters

	Reporting Period [s]	Average Transaction Rate [1/s]	Average Message Size [bytes]	Data Rate [bps]
Credit Machine in Grocery	120	0.00833	24	1.6000
Credit Machine in Shop	1800	0.00056	24	0.1067
Roadway Signs	30	0.03333	1	0.2667
Traffic Lights	60	0.01667	1	0.1333
Traffic Sensors	60	0.01667	1	0.1333

Table 9 shows the average data rates and reporting periods for residential applications.

Table 9 - Residential Applications Communication Parameters

	Reporting Period [s]	Average Transaction Rate [1/s]	Average Message Size [bytes]	Devices per Home	Data Rate [bps]
Smart Meters	9100	0.00011	20	3	0.053
Home Security System	600	0.00167	20	1	0.267
PHEV	4200	0.00024	12	2	0.046
				Total per Home	0.365

Table 10 shows the average density of devices in different areas.

Table 10 - Device density for cities

	density per Square Meter					
	Homes	Grocery Stores	Restaurants	Road Signs	Traffic Lights	Traffic Sensors
Urban (NYC)	0.00384400	0.00020947	0.00220000	0.00031647	0.00001503	0.00001503
Suburban (Washington)	0.00147922	0.00002312	0.00034988	0.00009433	0.00001144	0.00001144

Table 11 shows the average device quantity per gateway on different areas considering the radius where it is most likely that those devices will use SF=7, and its corresponding average traffic in bits per second.

Table 11 - Devices and Bitrate per gateway

			devices per gateway						
	Cell Radius [m]	Cell Area [sq. m]	Homes	Grocery Stores	Restaurants	Road Signs	Traffic Lights	Traffic Sensors	Total Devices
Urban (NYC)	200	125664	483.05	26.32	276.46	39.77	1.89	1.89	829.38
Suburban (Washington)	500	785398	1161.78	18.16	274.80	74.08	8.99	8.99	1546.79
			bps per gateway						
Urban (NYC)	200	125664	176.38	42.12	29.49	10.61	0.25	0.25	259.09
Suburban (Washington)	500	785398	424.20	29.06	29.31	19.76	1.20	1.20	504.72

This table shows that the required bandwidth is well below the maximum bandwidth per serving area according to section 3.3.

6. Powering and Backhaul Connectivity

6.1. Powering

Most standalone LoRaWAN 8 channel gateways on the market have a power consumption below 5W, even with 3G/LTE backhaul and embedded GPS. Using an embedded cable modem or ethernet connection to the fiber node instead of wireless backhaul can average a power consumption of 5W. This is well below the total power consumption of a traditional HFC fiber node, which ranges from 70 to 120W and 140 to 160W for a distributed access enabled node. Embedding the LoRaWAN gateway in the fiber node provides significant benefits on the powering area, as the gateway can be powered with the fiber node regulated power supply.

6.2. Backhaul Connectivity

In any LoRaWaN networks (Figure 11) a backhaul connection is required to connect the gateway devices to the application servers. In an HFC network model this backhaul can be provided by an embedded cable modem or direct ethernet connection in the fiber node. This approach provides a big benefit for the reliability of the backhaul, requiring negligible resources from the DOCSIS® network. As analyzed in the previous sections, an 8-channel gateway can require a maximum of 13.5 kbps of bandwidth. Compared to the hundreds of megabits available for DOCSIS® modems, this is it totally negligible. Given this, a real-time high priority delivery unsolicited grant service (UGS) service flow can be used on that modem in order to ensure immediate delivery of the information.

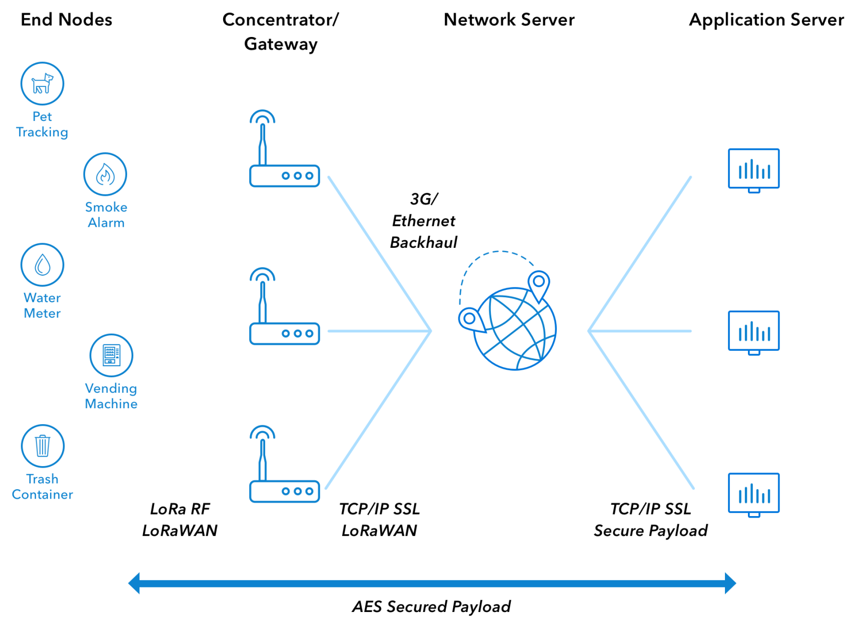


Figure 11 - LoRAWAN Architecture. Retrieved from TheThingsNetwork.

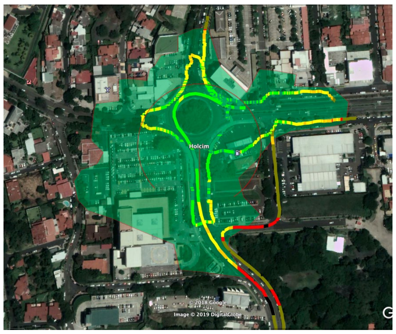
7. LTE Based IOT

It is really important to understand that LPWAN networks and LTE based IOT are not mutually exclusive options of IOT networks. As seen before, LoRaWAN provides a really good alternative for low bandwidth sensor applications like smart meters or city infrastructure support. On the other hand, LTE based solutions provide higher bandwidth capabilities and an evolution to support low power end devices as shown in table 12.

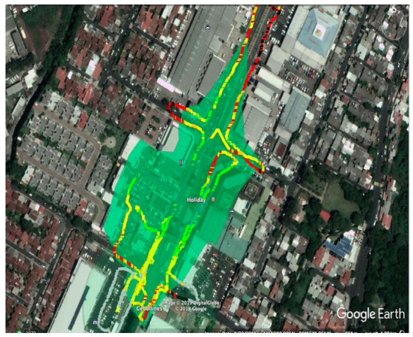
Table 12 - LTE IOT Protocols

	LTE Cat 0	LTE Cat M1	LTE Cat NB1
3GPP Release	Release 12	Release 13	Release 13
Downlink Peak Rate	1 Mbit/s	1 Mbit/s	250 Kbit/s
Uplink Peak Rate	1 Mbit/s	1 Mbit/s	250 Kbit/s (multi-tone)
			20 Kbit/s (single-tone)
Number of Antennas	1	1	1
Duplex Mode	Full or Half Duplex	Full or Half Duplex	Half Duplex
Device Receive Bandwidth	1.4 – 20 MHz	1.4 MHz	180 kHz
Receiver Chains	1 (SISO)	1 (SISO)	1 (SISO)
Device Transmit Power	23 dBm	20 / 23 dBm	20 / 23 dBm
Power	+	-	--

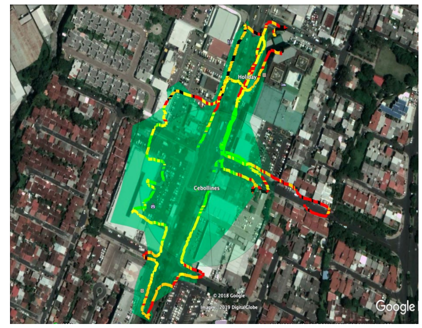
Even if this is not the main focus of this paper, there are several options of HFC backhauled LTE picocells which can provide access infrastructure for LTE IOT devices, in the three below pictures typical coverage for an LTE Picocell of 2W of power is shown.



Cell Diameter: 366m
Cell Radius: 183m
Cell Area (m): 50,691m^2
Cell Area (ft): 545,635 sq.-ft



Cell Diameter: 312m
Cell Radius: 156m
Cell Area (m): 22,304m^2
Cell Area (ft): 240,076 sq.-ft



Cell Diameter: 346m
Cell Radius: 173m
Cell Area (m): 17,773m^2
Cell Area (ft): 190,873 sq.-ft

Comparing the coverage of these LTE picocells with LoRaWAN gateways it can be seen that the coverage is really similar and in line with the size of an HFC fiber node.

Conclusion

This paper described the state of the art of current low power area networks for IoT, then analyzed the key parameters related to link budget calculation a bandwidth capacity for LoRaWAN networks serving urban and suburban areas.

Next, the best coverage zone for these areas was calculated and correlated that with different HFC network designs, followed by a sensor density and required bandwidth for that optimal coverage zone. Power and Backhauling was analyzed using the fiber node as connection point.

Lastly, a brief comparison between LTE based IoT and LoRaWAN was shown, focusing on their differences and how they can be both deployed on HFC Networks.

As a final conclusion: HFC networks provide the right supporting infrastructure to add support for IoT networks without significant effort. Wireless coverage zones are well aligned with fiber node locations and provide required power and IP connectivity. Adding IoT services can provide MSOs with an extra revenue stream without a significant investment and allow them to provide appropriate services.

Abbreviations

AP	access point
bps	bits per second
dB	decibel
DOCSIS	data over cable service interface specification
FEC	forward error correction
GPS	global positioning system
HFC	hybrid fiber-coax
Hz	hertz
IoT	internet of things
IP	internet protocol
ISBE	International Society of Broadband Experts
ITU	International Telecommunications Organization
IPSEC	internet protocol security
KPI	key performance indicator
LPWAN	low power wide area network
LoRaWAN	long range wide area network
LTE	long term evolution
MAC	media access control
MSO	multi service operator
OTT	Over the top
RF	radiofrequency
SCTE	Society of Cable Telecommunications Engineers
SNR	signal to noise ratio
UGS	unsolicited grant service
WAN	wide area network
WiFi	wireless fidelity

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