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Evaluation of Frequencies for the IoT Telemetry in Smart Agriculture

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Abstract

The IoT is becoming a widely known technology for the gathering of telemetry data, while mostly the concept of Smart cities is usually seen as the most challenging area for implementation. The different situations can be found in the smart agriculture concept, where different requirements and especially conditions exist. The purpose of this paper is to make an overview of IoT frequency bands available, with special focus on the situation in the EU, their theoretical usability and, using experimental measurements of typical background noise in different bands and calculations of transmission reliability on expected distance, estimate the practical usability of those technologies in the smart agriculture, compared to the smart city's requirements. Most of the IoT installations outside 5G systems are in the 900 MHz band, but is this well-suitable for smart agriculture?

Keywords

IoT, LoraWan, Sigfox, telemetry, FSPL.

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Introduction

The smart agriculture concept expects achieving and use of the right data at the right moment – mostly immediately when needed or when they become available. When working with data readings from the field (terrain) either long-term readings may be used – obtained on a time-to-time basis by aerial photography, satellite measurements, drones, or land-based agricultural vehicles, when they perform any agricultural operation. This is used for data with long-term validity, which are expected to stay unchanged by nature or any other expected effects. To gain access to field-measured data more often, there are several techniques available. The old-fashioned way is always to physically attend to the location and measure the required values or retrieve a memory device with on/site recordings. This approach limits the usability of such acquiring data due to the random character of measurement intervals, location on points within the area, physical capabilities of an explorer and covered area. Theoretically, possible solutions may be based on fixed sensors (or sensor stations) in terrain, connected to the data concentrator using fixed-line, such as RS-485, Ethernet or a different proprietary standard. This would provide needed data in an online regime, two-way communication, but is difficult to build up, especially in rural areas, fields, and forests. Having as much data from terrain is crucial for making the right decisions (Šilerová et al., 2019).

A typical data, obtained in the industry and smart city environments, focus on the energy, parking (Chatzigiannakis et al., 2016), lighting, etc. (Zanella et al., 2014); all at a high rate of measurements in time, causing a massive demand for data link capacity and multiple access. On contrary, in an agricultural environment, a different type of data and frequency of their acquiring is required (Playán et al., 2018). According to (Koprda et al., 2017) mainly weather, humidity (Jeong et al., 2018), wind direction, and strength values are needed in such conditions. Those readings are made much rarely, not creating a massive machine-to-machine communication (MMC), but devices are spread out on significantly larger distances. Thus approaches, typical for a Smart city/smart campus solution may not be the best for smart agriculture too and a different point of view should be used. A different type of data may be gathered from agricultural machines, tractors, harvesters, etc. Those sources are not present in terrain all the time, they are equipped with a high capacity power source and are large in size. This paper won't focus on such devices, while they are perfectly capable of using more traditional mobile networks.

New technologies in the 20th and 21st centuries allowed us to retrieve such data using automatic remote-controlled devices. These telemetry (téle – remote, métron - measurement) devices can operate independently and automatically transmit measured data. Those transmissions may be either one-directional (blind transmission) where the device transmits in given time intervals or when the measured value got changed, but without possibility to receive commands and acknowledgement, or bi-directional when a device can be called (addressed) for control purposes. Currently, two main groups of technologies may be used. First, based on one-use units usually build on a case-by-case basis with integrated radio modem and second, so-called IoT (Internet of Things) devices (Atzori et al., 2017) which tend to be more universal, mass-produced, and usually cheaper in terms of purchase. However, the authors of this paper would like to focus on, whether is a low price a regular reason to use such technology in agriculture.

Those commercially available technologies span through a wide variety of prices and capabilities, so far, no structured comparison of them was made for agricultural use. This paper will partially use results from (Stočes et al., 2016) and extend them by previously mentioned in-house solutions that were used in previous years and are still competitors to them.

The IoT is not just one technology, but several different techniques of how to get small amounts of data from the field to the processing point (Centenaro et al., 2016). What is common for all of them (techniques) is an expectation of very low bitrate (in 10s or 100s bits per second), low power usage on terminal devices-often battery-powered, small physical dimensions, and installation at non-dominant sites (terminals). This creates a situation very different from classical computer networks and using legacy approaches for the development and implementation of this technology would result in unexpected, unwanted, and too expensive solutions without practical usabilityMost of the IoT studies are focused on city-wide (Centenaro et al., 2016) or industrial use (Shete and Agrawal, 2016), while rural areas are not mainstream of interest. Not only IoT but multiple-layers telemetry technologies are introduced in this area – usually when a mobile phone is used as a concentrator (Granulo et al., 2016)[or GSM (Groupe Spécial Mobile – European standard for digital mobile networks) module (Sarri et al., 2017). But those areas are quite different from previously mentioned in terms of distances, power availability, hostile environment on fields (Parada et al., 2017) - so different approaches and technologies may or should be used. What is common for the smart city concept (Mikhaylyuk et al., 2018) are short span distances (100s of meters) (Centenaro et al., 2016), high or extreme high density of end devices within the premises and expect a lot of interference and background radio noise. On contrary, for smart agriculture, there is expected a much longer span distance of the links between the base station (concentrator) and measurement nodes (kilometres and more), low density of installations and less artificial electromagnetic interference. For both situations, wireless communication is used, using advantages such as instantaneous network build-up, no need to gain access to the premises between the nodes, nomadic or even mobile nature of devices. But without physical media, those networks suffer from disadvantages including, but not limited to, uncontrolled environment, extreme energy attenuation during transport, interference both natural and artificial.

For wireless data transmission, various frequencies can be used (Akpakwu et al., 2018), with different nature of different bands – ranges of frequencies with the common usage and/or behaviour. Those bands are co-originated worldwide by ITU (International Telecommunication Union) and regionally by national regulators. The lowest usable band for telemetry applications is VHF (very-high frequency) 160 MHz, which was widely used even in the analogue era in the 80´s-90´s of the 20th century. Such frequencies are capable of non-LOS (line-of-sight) applications because they can penetrate solid objects with still reasonable attenuation. Also, the construction of the high rf (radiofrequency) power output devices is possible using standardized components. The main problem with this band is in all developed countries caused by overloading shared frequencies by so many existing devices both legacy and digital from the pre-IoT era.

The second usable frequencies are in the “70cm” UHF (ultra-high frequency) band neighbouring 430-450 MHz local communication networks at the lower end of the existing television IV band. In this band, typically remote controllers, signalling devices with low reach and walkie-talkies. In this band, the uninterrupted LOS is required while those frequencies are way more attenuated when penetrating solid objects. On contrary, more bandwidth is available and almost no analogue co-existence is expected.

The last considered band is 900 MHz, close to the original GSM mobile band. Channels around 868 MHz were recently adopted for IoT usage and thus the main expected advantage was the lack of interfering and competitive appliances since the key-ratio (% of time used for transmission vs % of the time without transmission) is limited to 1% according to the ERC-REC 70-03 (CEPT Electronics Communication Committee recommendation). Due to the nature of such high frequencies, also antennas dimensions can be shorter and for end nodes (sensors) devices omnidirectional antennas with a gain of 0 can be used.

One of the differences from well-known RLANs (Radio Local Area Network), 802.11, GSM, and LTE are very low power transmitters, working at +14dBm (Europe) or +20dBm (North America) and extremely narrow bandwidth at 125 kHz (LoRaWAN) or 200 kHz (SixFox). A shared (ISM) band is always used for IoT regarding the regional specifics. The typical and most used band is 867-869 MHz in Europe, 902-928 MHz in North America. But not only are those intended to be used for the IoT. According to the ITU following bands are expected to be used for the "dedicated wide-area technologies" – 169, 420, 460 MHz which are legacy bands used for analogue and direct digital telemetry in the past. So there are more options available for the same purposes (telemetry) and for all of them, the IoT is one of the possibly used technology. Despite this, only one band is used in real applications and other options are usually even not taken into consideration.

Therefore, the main objective of this paper is to theoretically calculate and by a practical measurement check compare, which frequency bands are suitable for telemetry in smart agriculture – precision farming, where specific conditions with large distances and low device density exist.

Materials and methods

The authors firstly calculated the estimated maximum link distance for different frequencies. Due to the nature of radio waves distribution, a span distance for each radio-hop (the link between two points) differs according to the exact frequency used. The higher frequency is used, more electromagnetic energy is attenuated by the environment during propagation. This is caused by different energy spread and absorption of energy in materials, including molecules of air gases, for different frequencies. Following those estimations, an experiment was made in terrain, to measure typical background noise levels in different frequency bands in the rural area and on university campus within the city.

Theoretical calculations

For the calculation of theoretical link length, an FSPL (Free Space Path Loss) can be calculated using Formula 1 (Oluseun et al., 2020):

$$FSPL = 20\log_{10}(d) + 20log_{10}(f) + 20log_{10}\left(\frac{4\pi}{c}\right) \quad (1)$$

Where "*d*" stands for link length, *f* is the frequency [MHz] of a transmitted signal and "*c*" is the speed of light.

This formula can be, however, used also to calculate the theoretical maximum distance for radio links when the frequency and FSPL value are known. The FSPL value is calculated from the known maximum power output of the device (given by the regulatory) and the total gain of all passive parts of the radio link – in Formula 2:

$$d = \sqrt[20]{10^{FSPL-20log_{10}(f)-20log_{10}\left(\frac{4\pi}{c}\right)}} \quad (2)$$

With results in meters for ideal radio link conditions without interference (artificial or natural). In the real environment, those conditions are usually degraded by an object near and/or within the Fressnell's zone.

Also, for any data transmission technology, the theoretical bitrate can be calculated using the Shannon–Hartley Formula 3 (S-H) (Rioul and Magossi, 2015):

$$C = B\ log_2\left(1 + \frac{S}{N}\right) \quad (3)$$

Where "*B*" stands for the bandwidth needed for successful data transmission of desired speed (*C* in bits per second) in current noise conditions (signal "*S*" to nosise "*N*" ratio). This ratio is, as shown, unitless and both values can be measured either in dBu or dBm units.

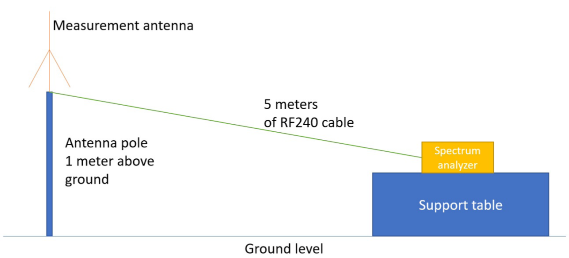
For the first part of the study, theoretical calculations were made with known values and expectations of the noiseless environment – as the "*N*" value for the S-H formula is very low. While measured levels of signals are usuallyin ranges of -10s dBms (typically -90 dBm) the noiseless environment was simulated by the level of -200 dBm. The "*S*" parameter was replaced with the sensitivity parameter of the receiver and the only unknown value left was the "*d*" parameter from Formula 2 – resulting in the wanted theoretical link distance for each technology and frequency band.

In the radio-link chain, calculations of the parameters of antennas must be taken into an account too when the most interesting parameter is the antenna gain. This gain is given by the physical dimensions and design of the antenna and is displayed either in dBi or dBD units. The dBi value compares (because all dB-based units are a relative type) the amount of energy radiated or received in the "main radiation direction" compared to the "isotropic" theoretical antenna, where all energy is radiated from the theoretical point in the space equally to all the directions. The dBD value is valid for the same antenna when energy levels are compared to the "dipole" type of antenna, which is a practical open-wire antenna with a length of 1/2 lambda (wavelength) split into two parts. The dBD value of the same antenna is approximately 2.15 dB higher than the dBi value.

To increase the gain of the antenna, the radiation diagram must be altered either in a vertical or horizontal direction. For the IoT applications mostly 0 dBD antennas are used on end-devices (terminals) and higher gain antennas are installed at base stations. The actual gain of the antennas depends on frequencies used while the omnidirectional characteristics (at horizontal level) is expected not to be altered. By extending the physical size (length) of the antenna, a higher gain can be reached but the reduction of the vertical radiation diagram as a result too. For the calculations, selected antennas are shown in Table 1, together with threshold sensitivity parameters of selected IoT terminal devices, calculated as the median of values from products datasheets of the IoT modules available at the European markets for respective bands (LPWAN SX1278, RA-01 SX1278, LPWAN SX1276, LoRa32 GPS NEO-6M, Semtech SX1276RF1IAS). While all IoT base stations and terminals use antennas directly connected to the transmitter (or integrated units) there is no need to take attenuation of the cable into account. The calculation for each frequency starts with the power of the transmitter in the worst scenario – the terminal unit, which is battery powered and its output power is limited by requirements for the long-live duty cycle. The typical power outputs for different bands are summed up in Table 1 while limits are governed by the previously mentioned ERC REC 70-03. Then the gain of one (base) antenna is added and with the knowledge of sensitivity threshold maximum allowed FPSL is calculated. From this result, limit span distance is calculated as a result of each frequency band.

Experimental measurements

In the second part, the real "N" parameter in the Shannon–Hartley formula was measured and calculated. Measurement of the background noise was performed in real conditions, while the university environment provided usable examples of both "urban" and "rural" environments. The university campus (WGS84: 50.1283828N, 14.3733025E) is located in Prague city, the capital of the Czech Republic. The second location (WGS84: 50.0694042N, 13.8861089E) was a field near Požáry village within Křivoklátsko protected landscape area, which is a typical European rural area. Field measurements were performed on the 16th and 17th of October 2020, each day during midday (11-12 hours) and evening (18-19 hours) on both sites for 30 minutes of continuous measurement. During all measurements, the weather was clear, without rain, temperatures from 18 to 22 Celsius. Values used in calculations were calculated as a median of measured values. Measurements in the field were made using a standardized set-up (Figure 1) with the ultra wide-band measurement antenna Sirio SD 2000 U / N which is capable of receiving in bands 130-160, 221-445, 610-682, 60-960, 1075-1500, 1610-2000 MHz and equal gain of 2dBi for all ranges below 1 GHz. An antenna was connected by a low-noise Belden RF240 PE cable of length 5 meters. Attenuation of the cable is previously checked and measured using the precise generator and obtained correction factors as in Table 2. This setup is connected to the spectrum analyzer FSL6-06 (1300.2502.06) by Rohde and Schwarz and is displayed in Figure 1. The whole set was battery-powered.



Source: own work

Figure 1: Measurement set-up

In this configuration the IoT base station (data collector) were simulated, while it is expected, that background noise would affect mostly this device and not the end nodes. Also, several IoT applications use only one-way communication where the receiving party is a base station.

According to the measured “*N*” parameter, a fixed SNR (signal-to-noise ratio) of 10 dB was added, the typical required capacity of 10 kbit/s is used and the resulting minimum received level is calculated. 15 dB reserve is set from the catalogue parameters of the IoT devices where required SNRs for different spreading factor varies from 7.5 to 20 dB.

From the known required level and known equipment parameters (tx power, antenna gain) maximum real link distance was calculated and real coverage for the selected technology was revealed.

On each location, the antenna was mounted to stand at a height of 1 meter above ground and measurements of the received energy in a 200 kHz window surrounding the centre frequency were made with an analyzer set to measure the maximum value of 1000 independent measures. This allowed authors to calculate with the pessimistic values and simulate “worst conditions”.

Results and discussion

Calculations

In theoretical calculations, the FSLP was calculated from existing values of frequency, power output limit and typical sensitivity of devices using Formula 1, from such values a „d“ parameters (Formula 2) were deduced and the length of theoretical maximal span distance for noiseless conditions was calculated (Table 1).

Those calculations clearly show that sensitivity levels, provided by the manufacturers of the IoT devices, selected as typical products available on market and mentioned above, cannot be taken as a valid parameter for the planning of the network. And for real span distance limits a real measurement had to be made. The reason for such extreme results (tens of kilometres) is also caused by not mentioned (in the datasheets) predicted reserve for the fade of 30 dB. For theoretical data bitrate, in a noiseless environment, noise level -200 dBm is used and bandwidth od 125 kHz (Table 2).

Measurements

Experimental measurement results started with the cable calibration, where exact attenuation of antenna-analyzer cable for different frequencies was to be later used as a correction. A well-known power level was applied to the cable, while the exit level was measured (Table 3).

An experimental set-up was established on both sites and the noise level was measured, cable attenuation from Table 4 was added as a correction.

For all bands, the rural area noise level is significantly lower than the urban one.

From measured levels and already known parameters of devices, expected link (hop) distance is calculated in Table 5 (pessimistic estimation for 30 dB fade reserve).

Centre frequency (band)	Transmitter output	Typical small device antenna gain	Typical device sensitivity	Available energy for FSLP	Theoretical span in noiseless conditions
169 MHz	+27 dBm	3 dBi	-129 dBm	159 dB	12 581m
433 MHz	+10 dBm	3 dBi	-132 dBm	145 dB	9 797m
867 MHz	+20 dBm	7 dBi	-136 dBm	163 dB	38 867m

Note: Transmitter outputs are regulated by international rules, used values are maximums defined by CEPT regulatory for respective ISM bands - ETSI 300 220-1 V2.4.1.

Antenna gain is used for antennas typical for small size devices, such as field sensor setups.

Typical device sensitivity is a mode of commercially available sets of rf modules capable of IoT (LoRa) transmissions at the time of the paper preparation. For 169 and 433 MHz bands, only universal rf modules were available.

Source: own calculations

Table 1: Calculated signal attenuation and maximal hop distance for the noiseless environment.

Frequency band	Bitrate available for the noiseless environment at the edge of coverage
169 MHz	86.6 kbit/s
433 MHz	89.3 kbit/s
867 MHz	91.4 kbit/s

Source: own calculations

Table 2: Theoretical bitrate for noiseless environment is sufficient for all expected purposes.

Frequency used	Generator power	Measured energy	Cable attenuation
169 MHz	-70 dBm	-70.48 dBm	0.48 dBm
433 MHz	-70 dBm	-70.82 dBm	0.82 dBm
867 MHz	-70 dBm	-71.15 dBm	1.15 dBm

Source: own calculations

Table 3: Cable calibration values (attenuation of the signal in measurement cable) measured before experimental measurement on sites.

Measured frequency	Urban area	Rural area	Cable attenuation
169 MHz	-84 dBm	-91 dBm	0.48 dBm
433 MHz	-87 dBm	-94 dBm	0.82 dBm
867 MHz	-92 dBm	-97 dBm	1.15 dBm

Source: own calculations

Table 4: Results of experimental measurements- background noise levels in terrain for three different bands in different areas.

Frequency used	Urban area	Rural area	Cable attenuation
169 MHz	1 258m	2 816m	0.48 dBm
433 MHz	693m	1 552m	0.82 dBm
867 MHz	616m	1 095m	1.15 dBm

Source: own calculations

Table 5: Calculated maximal hop distances for different bands in noisy conditions.

The table compares the theoretical span distance of radio hop with assured reliability for three studied radio bands in urban and rural areas.

Calculated results proved, that all frequency bands available for the IoT telemetry devices can be theoretically used for extreme distances (Table 1), corresponding to the manufacturer's datasheets. But when used in the real environment, when existing background noise must be taken into consideration, those span distances are limited and for the city-wide use one kilometre or less (Table 5). In the rural environment, where less noise is present, usable distance extends to kilometres, which are fully suitable for standalone is-land-type IoT installations. Since VHF band (169 MHz) devices are practically nonexistent at the market (even in kit or modules), from remaining, the 433 MHz, seems to be the best solution when an independent network is built, while the 860-870 MHz band is currently occupied by commercial and country-wide networks. Unfortunately, no producer of commercial IoT solutions focuses on the EU433 standards, while it would be usable in the smart agriculture and users of IoT in this area of application are forced to rely on the 900 MHz band, NB or even C-band solutions from country-wide providers. Results are focused mostly on European theatre as for the exact frequencies used (CEPT/ETSI) and power output limits.

Still, all mentioned bands for the IoT are well suitable for agricultural use with benefits of the IoT principles – small independent devices, used in régime „install and forget“. When comparing those bands, the main difference of agriculture use from smart cities concept is larger distances which need to be covered, thus even slightly better reach, shown in Table 6 as an increase of 50% in favour of 433 MHz, should be taken in consideration when projecting a new isůand-type IoT installation.

Frequency used	Theoretical span distance	Real span distance
169 MHz	12 581m	2 816m
433 MHz	9 797m	1 552m
867 MHz	38 867m	1 095m

Source: own calculations

Table 6: Comparison of theoretical calculated distances and distances calculated for the real environment.

Future research should focus on the creation of an experimental 433 MHz+867 MHz dual-band IoT island-. type installation in rural areas and comparison of the real coverage and reliability to a commercial solution. This would allow the researcher a continual measurement of signal parameters for a longer period and include the influence of weather conditions, such as temperature, air humidity on results. Those influences may cause different results, while weather situation is also a possible aspect of signal (including noise) attenuation.

Conclusion

In the paper, the authors show that not only 900 MHz band is available for the IoT applications and despite most authors nowadays planning and implementing new IoT solutions at higher UHF bands (900MH and above), the 70cm band (433 MHz) is an attractive alternative, with usability limited by the unavailability of commercial devices and lack of commercial coverage. But for self-managed island systems, made of modules it is promising to use this band for agricultural applications. Even when lower allowed power output, a better propagation of lower frequencies was shown in theoretical calculation using FSPL attenuation. When a background noise level was experimentally measured, the difference in favour to the 70cm band even increased. Those results should be confirmed by a longer continuous study with on-site installation in the future.

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