Combining Technology Innovations to Make IoT Implementations Cost-Effective and Sustainable

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Latest revision date - 20 March 2023

Abstract:

The objective of the following white paper is to provide readers with a better understanding of all the engineering and logistical challenges that are associated with large-scale Internet of Things (IoT) deployment and the ongoing operation of each of its constituent nodes. To illustrate the points raised, this white paper will give details of the collaborative work being done by Murata, Nexperia and Deutsche Telekom to encourage more widespread IoT proliferation. It will describe the multi-element solution that these companies can offer to customers to assist them with their IoT projects - where the wireless communication, power management and subscriber identity module (SIM) aspects have all been covered.

Introduction:

For much of the last decade there has been a great deal of media attention around IoT - and the smarter, ubiquitously connected world that it could enable. This would improve the crop yields in agriculture, boost the productivity of factories, result in better healthcare by monitoring patients from their homes, allow traffic congestion and air pollution issues within cities to be alleviated, etc. At international trade shows and conferences, it has driven debate and discussion. In a succession of reports, industry analysts have made ambitious projections about how many IoT nodes they expected would be in operation with certain timeframes. Unfortunately, the sort of figures envisaged have not yet been realized. Currently we are still at a stage where proof of concept IoT projects are being evaluated, and relatively small implementations are being undertaken in some disjoint sectors. This is still a long way from what had been originally hoped for.

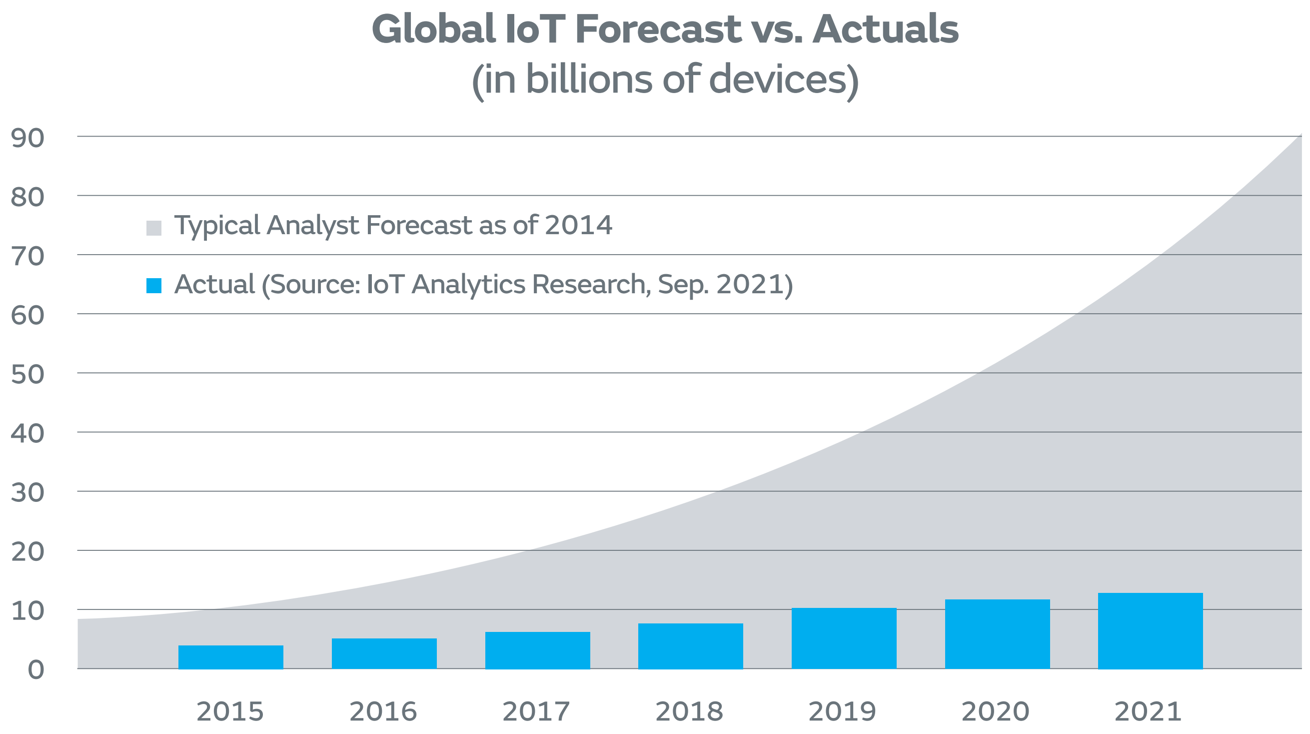


Figure 1:

IOT FORECASTS FOR 2015 TO 2021
AND WHAT HAS ACTUALLY BEEN ACHIEVED

There are several reasons why IoT roll-out has yet to progress beyond a nascent phase. Firstly, there is the total cost of ownership involved. Large-scale IoT deployments comprised of thousands (or possibly tens of thousands) of sensors are going to call for substantial upfront investments. That is just the beginning of course, since after all the hardware has been installed there will be the costs associated with maintaining an IoT device network's operation. So far, it has proven difficult for companies to accurately estimate what their return on investment (RoI) will be and within what timeframe they are likely to see the actual benefit of any financial outlay made on IoT infrastructure. This has understandably made many of them cautious to proceed at this point.

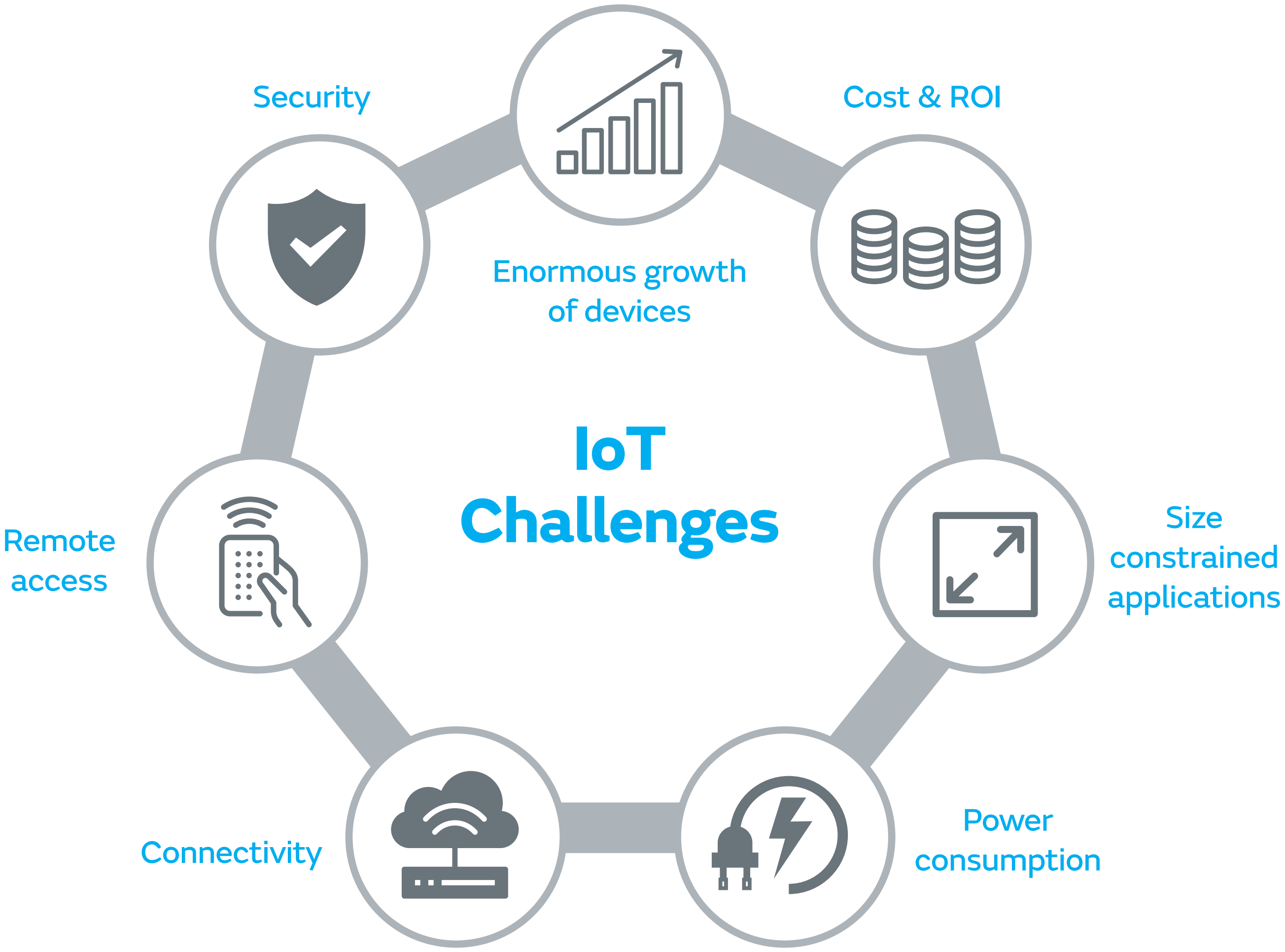


Figure 2:

THE MAIN CHALLENGES OF LARGE-SCALE IOT IMPLEMENTATION

The cost of implementation is frequently tied to the second key challenge of IoT implementation - namely the size of each device. Current designs will usually require the inclusion of multiple discrete components. This is neither conducive to limiting the size of the device nor to keeping its bill-of-materials (BoM) costs in check. Bulky devices featuring discrete components will have a narrow field of use, and cannot be employed in many of the high-volume, size-constrained applications that IoT technology is looking to attend to (such as goods trackers, body-worn medical devices, animal movement monitors, consumer wearables, etc.).

Smaller sized devices with higher degrees of integration will generally be more convenient to implement. With this in mind, IoT solution providers are continuously exploring different approaches in order for them to reduce the size of devices. However, it must be noted that it is difficult to do so without sacrificing the functionality that can be utilized or shortening the lifetime over which the device can remain operational.

The third key challenge, which interrelates to the second one, is how to power deployed IoT devices in the long term. There are two aspects to this - one being the energy available to each of these devices and the other being how efficiently they are able to use it. As will become clear later in this white paper, the current tactics for dealing with IoT power requirements are not particularly effective, even for small implementations - and when the size of IoT device networks expands, such problems will be further exacerbated.

To summarize the items raised here, before moving on, IoT infrastructure has to date been forced to rely on quite bulky and consequently expensive devices that are not really optimized for the applications they are targeted at. This has unsurprisingly held back commercial uptake. The period over which devices can be used is limited by their power requirements (with the only way of prolonging this being to get rid of some of the functionality or increase the device size). Consequently, though IoT has huge potential within a wide array of different application scenarios, it is still to see anything like the universal acceptance previously predicted. What is needed is the means to make IoT solutions that are more streamlined, with lower unit costs and more manageable power demands.

Redefining IoT hardware

Early IoT applications had to depend on full-scale connectivity solutions which were not at all optimized for the resource restrictions that use cases tended to have associated with them. This is why the 3GPP in Release 14 introduced the narrowband IoT (NB-IoT) cellular communications protocol. It provides a platform upon which low power wide area (LPWA) transmissions can be made, allowing 127 kbps downlink data rates to be supported while drawing very little power. As part of 3GPP Release 13, extended discontinuous reception (eDRX) and power saving mode (PSM) had already been introduced, with the intention of IoT devices being able to retain their power reserves by staying inactive for longer. eDRX is able to curb the power consumption by reducing the number of times that signals will be received while in standby, whereas PSM means a dedicated deep-sleep-mode during times of planned inactivity.

Though the NB-IoT module incorporated into an IoT device will need to be compact, it is important that efforts to reduce its size do not have a detrimental effect on the RF performance that can be derived. Also, it should be noted that because cellular LPWA has a relatively high output com pared to other short range communication topologies, tuning modules to meet the necessary standards compliance can prove difficult to achieve.

If 3GPP cellular operation is to be supported then the device will need to have a SIM. This will increase the board real estate needed by the device and add to its power budget too. A conventional SIM can use up to 5 cm^2 of area on an IoT device’s PCB (plus the related circuit paths) when plastic cards with sockets are employed. That can be problematic in situations where there is very little room available. Though SIM power consumption is small, when dealing with power-frugal IoT applications, any opportunity to keep this down will still obviously be advantageous.

> “*One of the largest component elements in an IoT device will be its energy storage resource.*”

One of the largest component elements in an IoT device will be its energy storage resource. This will normally take the form of a Li-Ion battery. Any reduction in its size will result in either the breadth of functionality that the device can support being restricted, or the period over which the device is able to operate being shortened.

If a longer-term operation is to be maintained then the batteries of IoT nodes will need to be replaced periodically. This can present a huge logistical challenge, however, as the costs associated with sending technicians out to swap batteries will almost certainly make the running of IoT networks consisting of thousands of nodes financially unviable - especially if nodes are situated in remote locations that are difficult to reach.

Furthermore, battery replacement will have environmental repercussions, as many of the materials used in them are pollutants. Society’s growing dependence on portable technology has driven up battery usage acutely over the last two decades. This has led to an increase in the mining of raw materials (such lithium, zinc, cobalt and manganese) in recent years. The mining, processing and eventual disposal of these materials all have unwanted ecological impacts. Another factor that needs to be considered is that there is only a limited supply of these materials.

Billions of primary batteries are thrown away each year - and these are a major contributor to the global e-waste problem already being experienced. If IoT networks are going to be reliant on batteries, then the damage done to the environment will be even greater, and the rate at which the reserves of rare metals employed in them are depleted is going to be dramatically accelerated.

> “*Billions of primary batteries are thrown away each year*”

The logistical and environmental issues that battery-based IoT arrangements present have driven research into alternative methods from powering devices, where instead of being completely dependent on batteries that will need to be replaced over time, the energy required can be extracted directly from the surrounding environment and transformed into electricity.

Energy harvesting technology has emerged as the means via which the power-related problems that the IoT is faced with may be solved. The energy from incident light, vibrations, RF signals can be leveraged - resulting in devices being able to run indefinitely without the need for battery substitutions (and the operational expenses that this will add).

By following a deployment strategy where energy harvesting is used, less room is needed for the energy storage unit (with the battery normally being replaced by a super-capacitor), resulting in device miniaturization. IoT devices can continue to operate indefinitely, with technicians no longer having to replace batteries when they run out. Until now, however, energy harvesting has come with considerable expense and power management ICs (PMICs) needed for such arrangements have required a large number of external components to accompany them, which all adds to the overall BoM and takes up space.

Based on NB-IoT technology, with an advanced integrated SIM (iSIM) built into it, and using energy harvesting to draw power, Murata, Nexperia and Deutsche Telekom have each applied their own specific expertise and present the **Autonomous NB-IoT Development Solution (ANDS)**. The ANDS will facilitate the development of IoT hardware that is cost-effective and sustainable, thereby overcoming the challenges already outlined and heightening the appeal of IoT technology. In the following section, the contribution of each company will be explained.

Elements included in ANDS

The first element of the ANDS that will be examined is its wireless communication capabilities. These are critical, as it is through them that data will be transmitted and received. Such activities are taken care of by Murata's latest NB-IoT module, the Type 1YS. With dimensions of 12.6mm x 10.6mm x 1.8mm, this is recognized as one of the smallest NB-IoT module in the world to be compliant with 3GPP Release 14 (NB2) - which means that it is suitable for use in even the most space constrained of applications environments. With eDRX and PSM function modes, the Type 1YS is highly power efficient. Its current consumption while placed in standby is just 3.5μA (typical).

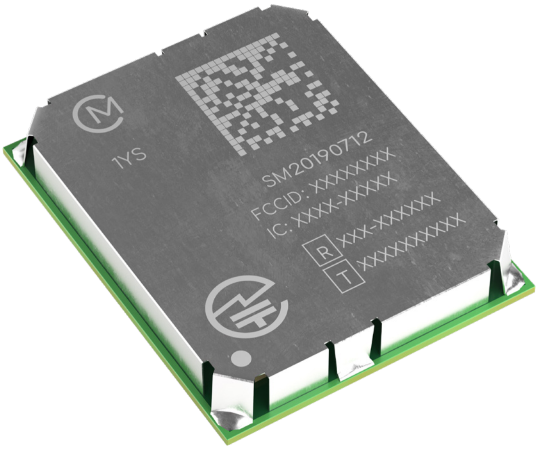


Figure 3:

THE TYPE 1YS NB-IOT MODULE FROM MURATA

The Murata Type 1YS module has Deutsche Telekom's groundbreaking nuSIM technology inside. Being an integrated SIM (iSIM), it avoids valuable board real estate having to be assigned, as everything is integrated directly into the radio chipset inside the module. This eliminates the use of plastic SIM cards, SIM sockets and related components. Device manufacturing costs can thus be significantly reduced, in line with the need for upfront IoT costs to be kept as low as possible.

Figure 4:

FROM SEPARATE SIM TO iSiM : DEUTSCHE TELEKOM'S nuSIM

nuSIM also avoids the slow external interface. SIM communication goes much faster, thus reducing the time for network attach, with less power to be consumed. Another impact: Removing the need for continuous SIM presence detection (where the device must check at regular intervals that the SIM is still in place) also helps IoT devices to save power.

With a conventional SIM, the subscription parameters come inside the SIM supplied by the operator that was chosen. nuSIM instead, is independent from any operator until a profile has been loaded. Such profiles are digitally delivered by the selected operator in the form of tiny, encrypted files of less than 1 kB size. A profile can be loaded to the nuSIM inside an IoT device at any point - during module manufacturing, module distribution, device manufacturing, or device shipment. There is even the option to do this over-the-air once devices have been deployed. After the profile is loaded into nuSIM, and the contents are decrypted and installed, it behaves exactly the same as a conventional SIM would.

As well as the cost and operational plus points of having IoT devices with integrated SIMs, the benefits from an ecological perspective should not be overlooked. Conventional SIM cards are supplied in credit-card sized plastic carriers. Given that there will be billions of IoT devices being deployed over the course of the next decade, an integrated approach will allow the generation of huge amounts of plastic waste to be completely avoided.

Finally, there is the PMIC. Nexperia has employed capacitive converting to reduce the BoM relating to its ultra-compact NEH2000BY product offering. Supplied in a 16-pin QFN package with 3mm x 3mm dimensions, this PMIC only requires a single low-cost capacitor to be placed alongside it. The footprint taken up by the energy harvesting element of the ANDS is thus negligible (far smaller than what can be attained by the competition). It takes up as little of a tenth of the space that would normally be needed.

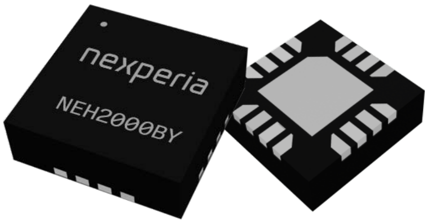


Figure 5:

NEXPERIA'S NEH2000BY ENERGY HARVESTING PMIC, ONLY 3MM X 3MM

Nexperia's capacitive approach has reduced the bill of materials of the NEH2000BY to just one external component costing less than $0.01. Besides the obvious size advantage, the assembly BoM of Nexperia's latest PMIC holds a cost advantage of more than $0.50 in most applications. This makes the NEH2000BY particularly attractive for large scale NB-IoT based implementations. need for upfront IoT costs to be kept as low as possible.

The Nexperia PMIC can manage the current coming from the specified energy harvesting source (such as a solar cell or a thermoelectric generator) covering values that start as low down as 10μW. Since ambient energy harvesting uses trickle charge to collect and store power, the average efficiency of a system driven by the maximum power point tracking (MPPT) algorithm of the PMIC is more important than its peak efficiency. With an MPPT settling time of 1 second, the NEH2000BY achieves an industry leading average power conversion efficiency figure of ~80%, performing well in tackling constantly changing ambient energy sources.

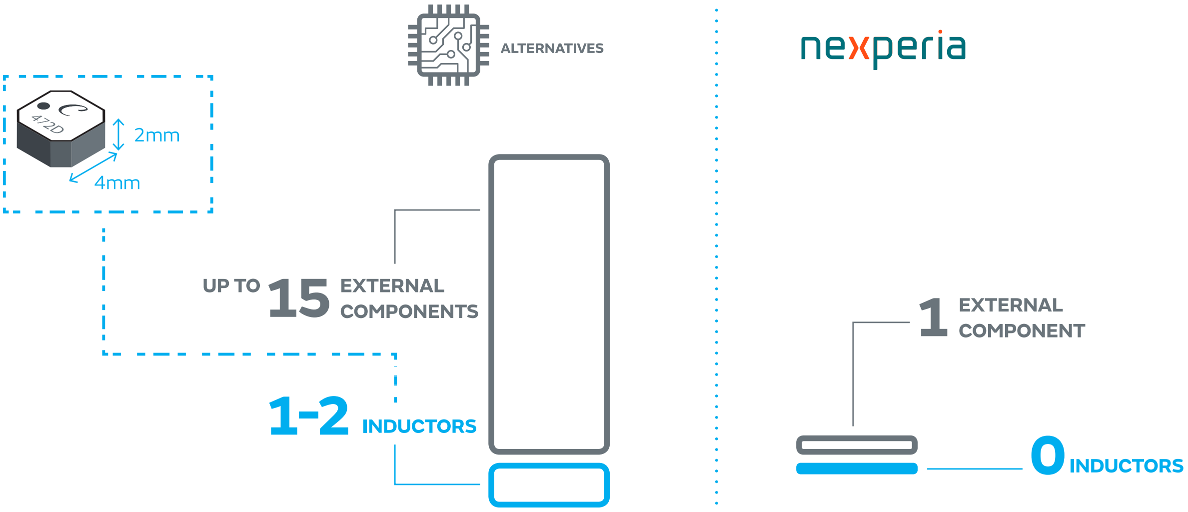


Figure 6:

COMPARISON OF THE NEXPERIA NEH2000BY BOM WITH RIVAL POWER MANAGEMENT SOLUTIONS

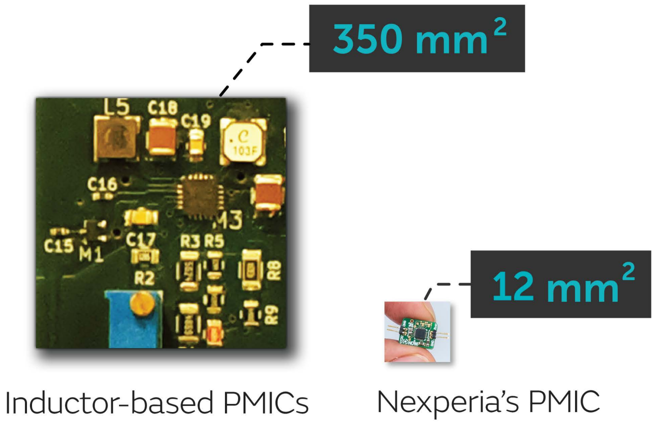


Figure 7:

NEXPERIA NEH2000BY ASSEMBLY SIZE COMPARISON WITH ITS COMPETITION

More about ANDS

As outlined, the ANDS combines Murata's Type 1YS NB-IoT module for transmission with Deutsche Telekom's integrated nuSIM for providing network connectivity and Nexperia's NEH2000BY PMIC to power the solution with ambient light energy. It also includes a small outdoor photovoltaic panel and a rechargeable battery to collect and store the ambient energy. A schematic of the different function blocks that this solution is composed of is shown in Figure 8.

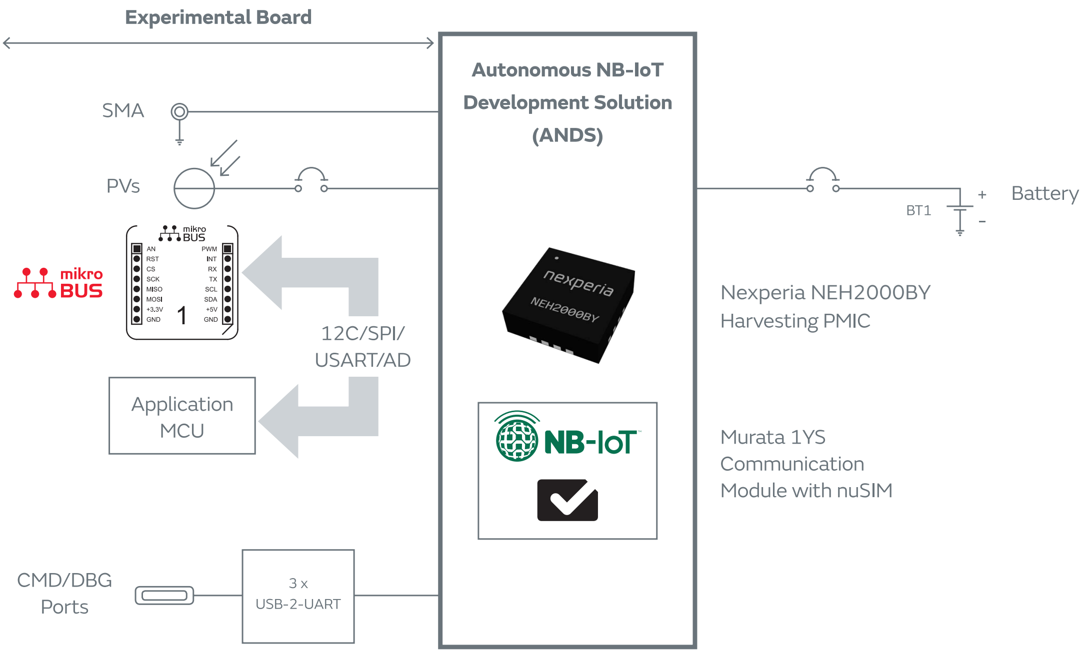


Figure 8:

ANDS FUNCTIONAL BLOCK DIAGRAM

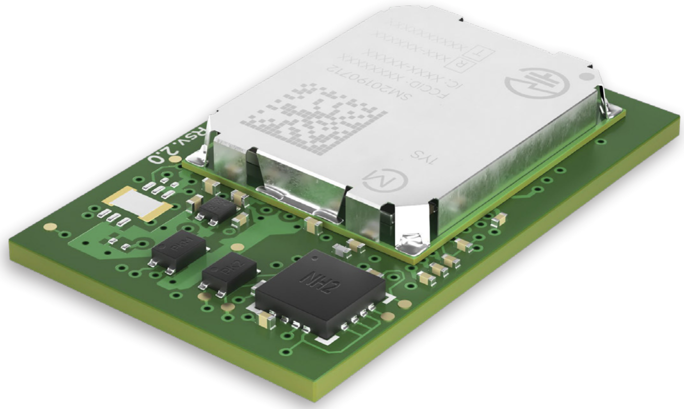


Figure 9:

THE ANDS FEATURING A MURATA MODULE (nuSIM INSIDE) PLUS A NEXPERIA IC, ON A 1CM X 2CM BOARD

Figure 10:

ANDS ON AN EXPERIMENTAL BOARD

Figure 10 shows the experimental board housing the ANDS. Here it is possible to execute test protocols and measure energy consumption data. The energy consumption of the ANDS solution has been measured for a complete cycle (covering wake up, connect, ping, light sleep). The following are the average values from the measurements obtained:

Mode	Current (mA)	Time (s)	Energy (mWh)
Wake-up	-	Immediate connection	~0
Connect	24.3	5.1	0.11
Ping	63.5	0.8	0.045
Light Sleep	2.1	20	0.039
Total Energy Consumed in one cycle*			0.19

*The energy consumption is highly dependent on the quality of network and the transmission power

As mentioned, the ANDS has a plug-in board, designed by Nexperia, with a photovoltaic panel. This provides the solution with energy autonomy via ambient solar energy harvesting. The Panasonic photovoltaic panel clips on top of the experimental board and is held in position using 4 spacers. The average charging current is 1.1mA at 3000lux (which represents a very cloudy outdoor environment).

Environment	Charging Current (mA)	Average Power (mW)	Harvested Energy mWh/day
3000lux for 6 hours	**1.1**	**2***	**12**

* The Nexperia NEH2000BY is in high power mode and operates at maximum efficiency up to 2mW

The harvested energy is 12mWh/day compared to a consumption of 0.19mWh for an NB-IoT transmission. Hence the set-up can achieve a high level of energy autonomy, with the capacity to support up to 60 NB-IoT transmission per day. By avoiding the need for battery replacement, the ANDS is a highly effective platform upon which to develop energy autonomous sensor nodes.

Having looked at the power generation aspect, next the network connect and disconnect times in relation to nuSIMs and conventional physical SIMs (and the power budget implications) should be investigated. The ANDS experimental board has a legacy physical SIM slot, therefore it is easy to compare the performance of both SIM types. The test conducted here was based on 50 connection/disconnection events run via an automated Python script. The results are presented in the table below.

Measure	CONNECT TIME (S)		DISCONNECT TIME (S)	
	nuSIM	Physical SIM	**nuSIM**	Physical SIM
Mediam	7.3	11.3	10.6	14.5
Minimum	4.9	6.0	8.0	9.3
Maximum	17.2	39.2	13.1	26.7

The measurements show there is a consistent difference of approximately 4s in connect and disconnect times between the nuSIM and a physical SIM. The median values of the connection time highlight the fact that the nuSIM is ~35% faster than a physical SIM when connecting to the network. The disconnect time also has a similar pattern, with the nuSIM being ~27% faster at disconnecting from the network compared to physical SIM. The faster connection/disconnection times of the nuSIM-enabled ANDS leads to a much lower overall power system than can be achieved by its physical SIM counterpart. Please note, more details on this measurement set-up can be found in the Appendix.

Conclusion

It is clear that there are still significant challenges that are preventing mass market IoT adoption from being witnessed. The overall size of the devices and their power consumption are both important parameters in this respect, with any capacity to lower these likely to be invaluable. The unit costs of these devices will be critical from a capital expenditure standpoint, and the ongoing operational overheads must be properly evaluated too. By shifting to an arrangement where energy harvesting mechanisms and integrated SIMs are used, not only can these costs be brought down, but the environmental implications of IoT deployment may also be tackled - with less plastic needing to be produced and fewer batteries having to be disposed of. This is why the ANDS that Murata, Nexperia and Deutsche Telekom have presented in this paper is certain to be a real game-changer for IoT's continued progression over the years ahead. It will make IoT projects less costly to embark upon, more efficient during operation and altogether more sustainable.

More Information

Please visit the websites below

Nexperia | www.nexperia.com
Deutsche Telekom | https://iot.telekom.com/en/nusim
Murata | www.murata.com

Press Contact:

✉ **Aya Tonooka | atonooka@murata.com**

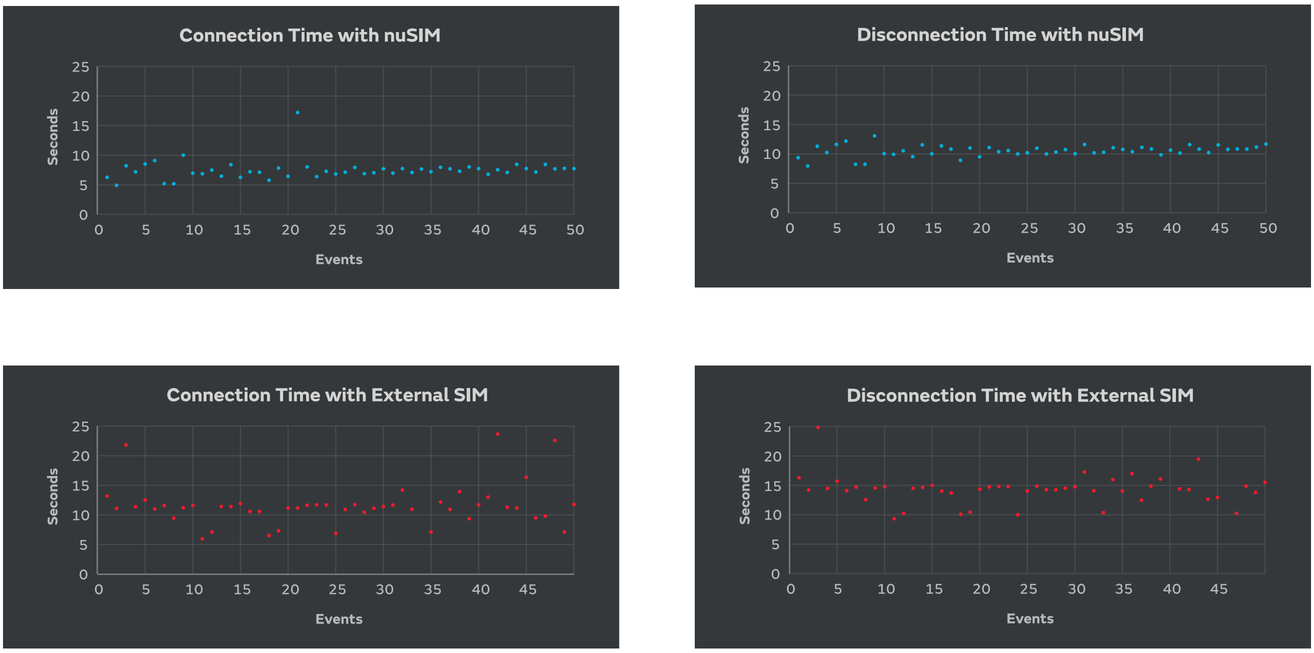
Appendix

Set-up and test protocol to measure nuSIM/SIM connection and disconnection time consisted of the following key elements

- An on-board microcontroller resetting the module at start-up then entering STOP mode
- 5V disabled
- 1.8V disabled
- The photovoltaic is unattached unless otherwise specified
- The on-board LDOs are driven by VBAT, supporting circuits are running from the battery
- Battery current is monitored
- On module 3.3V LDO is fed back as module VDDIO
- PA VDD is always ON
- COM port is connected to USB
- Test steps with manually entered AT commands
  - Connect network
  - Ping with 100 packets
  - Disconnect

A batch of 50 runs, with 60s delay, were run for both nuSIM and external SIM options. Each run required:

- Performing a software reset
- Connecting to the network
- Sending a 90byte payload
- Detaching from the network
- Collecting timing data



Connection Time with nuSIM

Disconnection Time with nuSIM

Connection Time with External SIM

Disconnection Time with External SIM

Figure 11:

CONNECT AND DISCONNECT TIME FOR nuSIM AND EXTERNAL SIM