

Everactive's Evernet Protocol: Unlocking the Internet of Things at Scale

Introduction

The Internet of Things (IoT) has been heralded as the “second phase of the internet,” promising to bring the “transformative technology’s business model from the digital to the physical world.”¹ Yet, despite its potential to generate tens of trillions of dollars in economic value, the IoT has continually fallen short of analyst expectations. The most basic limitation has been one of scale: realizing such enormous value requires wireless networks with such a high-volume of sensors so as to fundamentally challenge the boundaries of today’s technological capabilities.

In other papers, we’ve discussed the first-order scaling problem of power and the pitfalls of batteries. Trillions of sensors would require trillions of batteries, setting the world on a hamster wheel of battery maintenance that is simply too prohibitive from a cost, logistics, and sustainability standpoint to justify the benefits. For this reason (and others that we’ve outlined in our Battery Problem whitepaper), the trillion-node IoT must eliminate the battery. At Everactive, we’ve solved the battery problem with custom integrated circuits that operate entirely and continuously off low levels of harvested ambient energy. The result: always-on, self-sustaining, and battery-free wireless sensors.

After solving the power problem, one is faced with an additional technological challenge: wireless networking. Specifically, leveraging a wireless protocol that can not only operate at a low enough power budget to keep the battery out of the equation, but also simultaneously support:

- » High-density networks (supporting thousands of devices)
- » Low-latency operation (read: real-time communication)
- » Adequate data rates
- » Reliable range (both distance and penetrability through obstacles & interference)

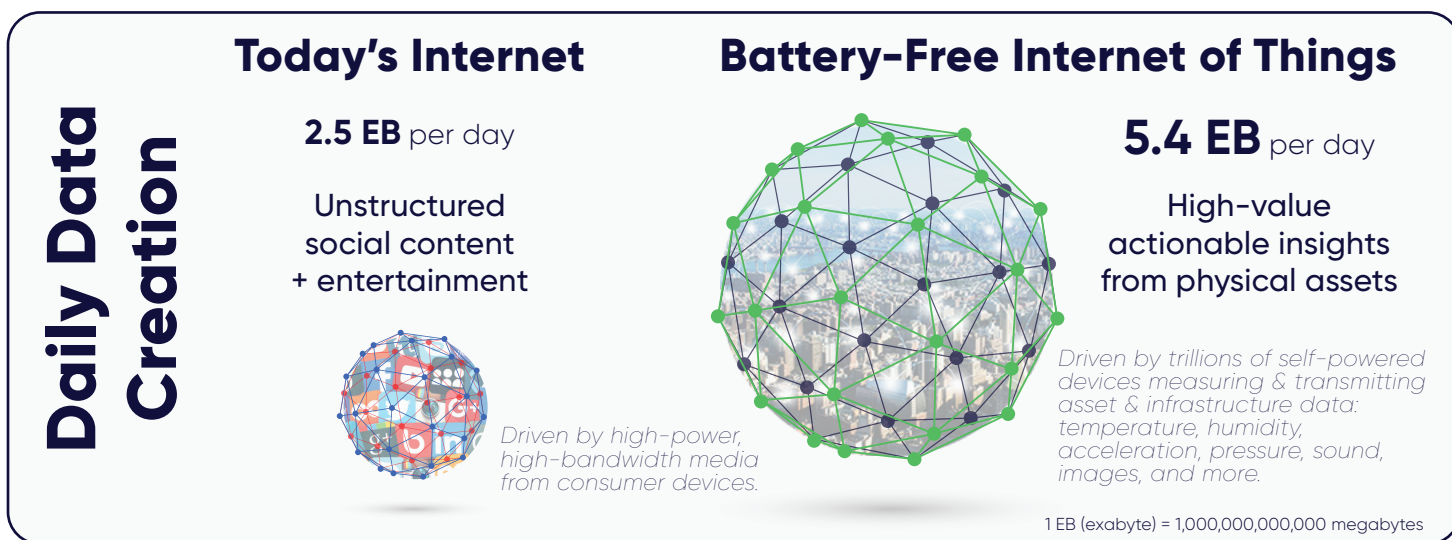
This paper will outline how Everactive has solved the IoT’s wireless networking problem with its proprietary Evernet protocol, delivering all of the above features within the company’s patented batteryless footprint.

Data is King: The Value of 1 Trillion Devices

The ultimate promise of the IoT is an explosion of digitized data from the physical world to improve the efficiency and quality of our lives across a range of settings—from our homes and cities to our factories and offices and everything in between.

According to the World Economic Forum, humanity will have generated roughly 44 zettabytes of data by the end of 2020.² That cumulative “digital universe” has been mostly formed by our collective Internet searches, messages, social media activity, and entertainment consumption; in other words, mostly digitally native data. The ultimate vision of the IoT will exponentially accelerate data creation as it endeavors to stream actionable insights from trillions of physical-world endpoints.

To be sure, not every IoT device will require the same data throughput as many of today's Internet-connected devices; in fact, the average battery-free IoT device will need very modest bandwidth relative to today's consumer devices. Even so, the numbers add up quickly. Assuming a conservative 500 bit per second average data rate, each day a trillion-sensor IoT will generate 1,350x the daily data created on Facebook, the \$700B social media goliath whose user base of 2.6 billion people accounts for one-third of the planet's population. A trillion-sensor IoT will more than double the already staggering 2.5 quintillion bytes of data created each day.³ Moreover, unlike the mostly user-generated data of today's Internet, the structured data of the trillion-node IoT will deliver measurable utility to our workplaces, communities, and all aspects of our lives.



As we continue to connect more and more “things” to the Internet, we will reap the rewards of processing and correlating more and more data. Indeed, Morgan Stanley expects the IoT to have a \$14.2 trillion impact on the global economy by 2030.⁴ Significantly, however, those financial forecasts are based on severely revised device estimates in the tens of billions, rather than the trillion-plus endpoints that analysts were predicting just a few years ago.⁵ If we continue to break down the technology barriers to realizing a trillion devices, imagine how much more impactful the Internet of Things can be.

Wireless Networks at Scale: Connecting 1 Trillion Devices

Solving the first-order scaling problem of power goes a long way to realizing the dream of a trillion-node IoT. It avoids the mind-numbing task of incessant battery replacements that would otherwise be required. Depending on your outlook on battery advances, such a world with battery-operated devices would require anywhere from 274 to 913 million replacements per day—certainly an unsustainable approach for a category of technology designed to improve efficiency!⁶

With the power problem solved, those trillion self-sustaining nodes need to now communicate reliably in real-world situations. Not only do they need to operate entirely from a harvested energy budget, but they also need to transmit meaningful data packets in as near real-time as possible through various physical obstacles and wireless interferers. Moreover, these nodes will have to do all of that while coexisting among extremely high concentrations of other devices.

So, what exactly will those wireless sensor networks look like with a trillion connected devices? Using the latest estimates of today's 30 billion connected devices and an estimated 40 million square miles of habitable land on Earth, we can approximate that there are 750 devices per square mile scattered across the planet.⁷ With one trillion devices, that figure jumps to 25,000 devices per square mile. Of course, devices are not distributed uniformly. Instead, there is some correlation between connected “things” and concentrations of people; more technology is deployed in and around population centers. If we were to allocate one trillion connected devices across the world's 7.8 billion people, we would have 128 devices per person. As seen in the table below, this would yield a staggering device density for both metropolitan areas and less populated cities. On average, the top 10 US metropolitan areas, which include both the urban centers and surrounding suburbs, would need to cram 193,171 devices into each and every square mile! But this is not just a problem for the world's largest cities. The device density for moderately sized cities, such as Ann Arbor, Charlottesville, and Santa Clara exceeds the top-ten average.

Device Density in a Trillion-Node Global IoT

Metro Area	Population	Devices	Area (mile ²)	Devices per mile ²
New York Metro Area	19,216,182	2,463,613,077	3,450	714,091
Los Angeles Metro Area	13,214,799	1,694,205,000	4,850	349,321
Chicago Metro Area	9,458,539	1,212,633,205	10,856	111,702
Dallas-Fort Worth	7,573,136	970,914,872	9,286	104,557
Greater Houston	7,066,141	905,915,513	10,062	90,033
Washington Metro Area	6,280,487	805,190,641	5,564	144,714
Miami Metro Area	6,166,488	790,575,385	6,137	128,821
Philadelphia Metro Area	6,102,434	782,363,333	5,118	152,865
Atlanta Metro Area	6,020,364	771,841,538	8,376	92,149
Phoenix Metro Area	4,948,203	634,385,000	14,598	43,457
Santa Clara	129,488	16,601,026	18	922,279
Ann Arbor	119,980	15,382,051	29	530,416
Charlottesville	48,117	6,168,846	10	616,885

For those following the emerging 5G standard, these device densities might sound familiar. Indeed, one of the many benefits of 5G will be its ability to support more than one million devices per square mile. However, the specified cellular standard focuses heavily on speed, throughput, and data volume, rendering it too power hungry of a standard to operate without a battery. The 5G cellular standard will do wonders for mobile video streaming, gaming, and a range of other high-bandwidth applications. However, in its current instantiation, it will not provide the answer to proliferating trillions of self-sustaining IoT devices. The 5G IoT standard must evolve to support battery-free operation. Enter Everactive's Evernet protocol.

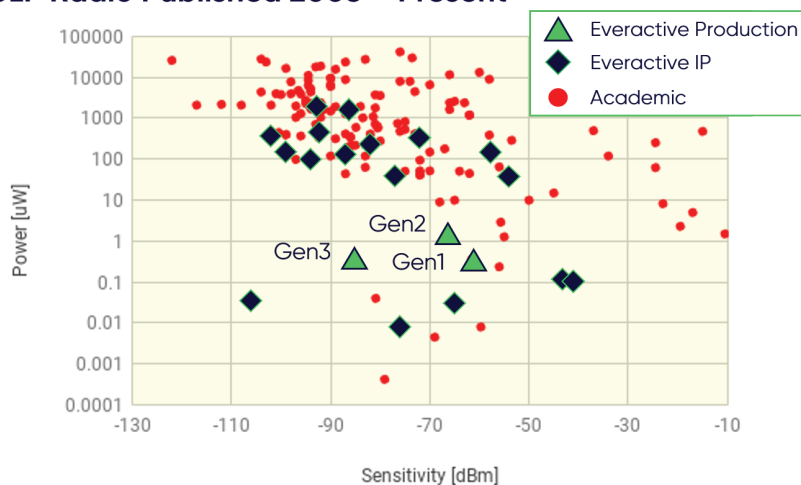
Evernet Technical Overview

Evernet is an FCC-compliant proprietary wireless networking solution designed to support a high density of batteryless devices. It takes advantage of Everactive's always-on ultra-low power (ULP) receiver to dramatically reduce power consumption, while supporting thousands of devices with millisecond latency and 250+ meter non-line-of-sight range.

Everactive achieves these breakthroughs by leveraging the always-on ULP receiver to handle all network synchronization traffic through an encrypted broadcast channel from its IoT gateways. Time synchronization is a necessary function in all wireless networks and this is often the most power-hungry function of any standard wireless protocol, such as Bluetooth, Wi-Fi, and LoRa.⁸ Time synchronization is how wireless devices efficiently share the wireless spectrum and how sensing and control functions can be coordinated across wireless links. The more precise the time synchronization, the more efficient the network can be, making it easier to scale device density and support higher throughput. For sensor applications that are primarily event-driven, meaning wireless traffic is light until an event is detected, most of a device's power consumption is spent on network synchronization.⁹ Because Everactive's always-on ULP receiver requires such negligible power (a mere 200 *nanowatts* when active), Evernet unlocks much higher performance. Effectively, it "inverts the network," allowing every device to be constantly listening to every broadcasted gateway message—all of the time. This means that the network is continuously synchronized with virtually no power penalty. Continuous synchronization means that Evernet can pack in more devices with higher average throughput, and low latency communication, to any one device. Everactive has fundamentally improved wireless network management, all within a harvested energy budget.

The plot in figure to the right shows how Everactive's ULP receivers compare to state-of-the-art published research results in terms of active power and sensitivity (a measure of wireless range). This plot highlights the 1,000x reduction in power compared to the best-in-class COTS receivers. For comparison, existing receivers such as Bluetooth and Zigbee range from 5,000–30,000W.

ULP Radio Published 2005 – Present



In addition to network synchronization, Everactive's always-on ULP receiver can decode basic operational instructions and process global and/or local network-level interrupts from IoT gateways or even other sensors. This adds an ULP communication channel for device provisioning or roaming instructions, control messages to devices, or even localization by triangulation. For routine bidirectional data traffic, an off-chip sub-GHz radio is used with a protocol adopted from the IEEE 802.15.4 standard. Because this radio is only used for data and not necessary for network synchronization, the average power for wireless communication is dramatically reduced.

Evernet also utilizes time division multiple access (TDMA) with a time slot assigned by the gateway over the always-on ULP receiver, and local timing references provided by our custom, fully integrated system-on-chip (SoC). Bringing these functions inside the SoC and using Everactive's proprietary ULP circuit design expertise reduces the power by 1,000x, while simultaneously improving the network performance as compared to other wireless standards.

Low-Power IoT Protocol Comparison

There are a number of wireless standards vying to be "the" IoT protocol. While each has their pros and cons, none of them are well-suited to support the trillion-node IoT.

Wi-Fi and Cellular narrowband IoT (NB-IoT) are perhaps the most ubiquitous wireless standards today, but each requires too much power to operate from a harvested power budget and thus must rely upon batteries. Even with a battery, however, these networks are too high-power to be able to communicate continuously. To last for any tolerable lifetime, Wi-Fi and Cellular IoT devices must significantly modulate transmission, at best sending data only a handful of times per day.

Other personal and local area networks (PAN, LAN), such as Bluetooth and Zigbee, offer lower power solutions, but their range is poor and they do not scale to large numbers of devices. They also require a smartphone or gateway nearby. These are sufficient for consumer applications (e.g., smart homes and wearables), but cannot be the answer for one trillion devices.

A newer set of wireless standards targeting the IoT are low-power wide area networks (LPWAN) such as LoRa and Sigfox. While these offer longer communication range, they do not support high data rates. Like Wi-Fi and Cellular, these protocols often limit the number of transmissions to only a handful of times per day, rendering them ill-suited for applications that require real-time insight.

One aspect that all of these protocols have in common is that they must "duty-cycle" their radios in order to achieve lower power consumption. This means that their radios are off most of the time to save power, and this is precisely why these solutions have higher latency, lower throughput, and spend a significant amount of power on time synchronization when the radios do turn on and need to reconnect with the gateways.⁸ Everactive's ULP always-on receiver technology overcomes the disadvantages of duty-cycling to provide a continuously operating radio that simultaneously achieves larger scale networks, longer range communication, and lower latency—all on a harvested energy budget.

The below table provides a comparison of competing low-power IoT protocols.

Protocol	Power	Time On	Range	Nodes per Gateway	Data Rate	Penetrability
Evernet	Batteryless	Continuous*	800 ft.*	1,000s*	0.25 Mbps	Strong sub-GHz
Zigbee	Low	Once per minute	100 ft.	20-50	0.1 Mbps	Weak 2.4 GHz
Bluetooth Low Energy	Low	Once per minute	100 ft.	20-50	1 Mbps	Weak 2.4 GHz
Sigfox	Low	1-2 times per day	> 1 mile	1,000s	< 0.1 Mbps	Strong sub-GHz
NB-IoT	Medium	Once per hour	> 1 mile	1,000s	< 1 Mbps	Strong Cellular
LoRaWAN	Medium	Once per hour	> 1 mile	20-80	< 0.1 Mbps	Strong sub-GHz
Symphony Link	Medium	Once per hour	> 1 mile	100s (w/ repeaters)	< 0.1 Mbps	Strong sub-GHz
Mioty	Medium	Once per hour	> 1 mile	1,000s	<< 0.1 Mbps	Strong sub-GHz
Wireless HART	High	Continuous	100 ft.	100	0.1 Mbps	Weak 2.4 GHz

* Supporting up to 1,000 Eversensors per gateway with less than 1% PER in a harsh industrial environment (path loss coefficient of $k = 2.37$)

The 5G community is looking heavily at adding IoT standards to accommodate a wide range of low-power devices and applications. These applications are broadly categorized as massive machine type communication (mMTC), targeting huge numbers of low-power devices, as well as ultra reliable, low-latency communication (URLLC), targeting industrial control and autonomous vehicles. Separate cellular IoT protocols are being developed to accommodate these two categories.

These protocols are built on top of the cellular framework; LTE today and in the future New Radio (NR). Because these IoT protocols share spectrum with the high-performance cellular protocols, even the IoT devices have strict performance requirements in order to avoid interference with incumbent devices. One such requirement is accurate time synchronization, which, as outlined above, benefits significantly from always-on ULP receivers.

Adopting protocols that take advantage of always-on ULP receivers can fundamentally change how IoT devices connect to the cellular network in future releases. Evernet is uniquely optimized to address these connectivity challenges, providing the mechanism to bring long-anticipated digitization to massive amounts of physical-world assets and infrastructure.

How Evernet Will Benefit Your Operation

Manufacturing plants, refineries, and other large campuses seeking to reap the benefits of IoT technology are faced with an array of choices spanning the entire technology stack, from sensor devices to cloud analytics platforms. How data is transmitted from those devices to those cloud platforms is a critical piece of the puzzle that has significant implications for installations and maintenance, scalability, and data reliability. Ultimately, choosing the right wireless network will play an important role in a solution's total cost of ownership and generated return on investment.

Everactive has applied its decade-plus research and development in the field of low-power wireless communication to solving the scalability, reliability, and cost challenges associated with deploying high-density sensor networks. The core ULP always-on receiver enables truly continuous operation so that customers can realize true real-time insight, without duty-cycling to conserve battery life. With a several-hundred-meter non-line-of-sight range, and a novel networking scheme that connects thousands of devices per gateway, Everactive delivers this insight with a minimal infrastructural footprint throughout customers' sites.

About Everactive

Everactive combines batteryless wireless sensors and cloud analytics to deliver end-to-end Industrial IoT solutions. The company's groundbreaking self-powered technology allows for low-cost, long-lived, and intelligent instrumentation of industrial assets that have previously been too expensive or dangerous to connect. Everactive's services provide high-value insights from newly generated and self-sustaining data streams. For more information, visit www.everactive.com

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