## How to connect all the things without using all of the power (green communications for IoT)

Consider the traditional cellular network, where there is a cell tower, and a random assortment of devices within the cell. Some devices will be closer to the tower and are outside, free of any obstructions. Other devices will be far from the tower, or indoor and have poor signal quality. Of course, there is a range of devices located between these two extreme cases. There are existing solutions to these type of problems today, such as microcells [1] which may be deployed indoors, and beamforming [2], to name a couple. However, often these approaches rely on infrastructure like wires or optical fibres to connect the wireless technology to the Internet. Everything is typically at most only a couple wireless hops away.

There is lots of hype around 5G being the savior technology, particularly with respect to IoT. 5G is often seen as the technology to connect all of the devices, however, it is increasingly becoming apparent that this is not the path to scalable, energy efficient communications [3][4]. In many of the proposed 5G solutions, every device connects itself directly to the Internet through the cellular network.

If instead, some proportion of IoT devices could reach the Internet through other devices (such as other IoT devices, mobile phones, automobiles, etc), with a good cellular connection through a different technology such as Wi-Fi, Bluetooth, Wi-Fi Direct, Wi-Fi p2p, multi-peer, LoRaWan or other similar technologies, the impact on energy requirements could potentially be reduced. Intel alludes to this type of 5G network - where the high capacity Internet connection is only used when necessary [5]. This type of technology is typically known as ad hoc networking, or mobile mesh networking. The connections between devices form in an ad hoc and unplanned way, which makes things like finding a path to the Internet quite difficult because there is little or no predictable infrastructure to make use of. However, the tradeoff is that you can connect many devices to a single Internet connection.

In addition to reducing the number of devices directly connected to the Internet, there are many other ways to improve communications efficiency. Selecting network protocols which allow for formation of clusters is another way. In this type of network, cluster-heads reduce the amount of direct signalling required to each device in the network.

In addition to clustering, techniques like caching and multicasting can be used in order to reduce the amount of data being requested directly from the Internet. This can be useful for pushing updates to the IoT devices themselves for example.

Finally, data aggregation can also occur in order to reduce the overhead of packets, and to pack as much data into packets as possible, rather than many small packets with bits of data from each IoT device / sensor. This also works well with clustering, as the clusterhead is a natural position for aggregating data to be sent to the Internet.

This article will first try to quantify how much energy is currently used worldwide by communications networks. It will then estimate how much can be saved if green communication techniques are used.

**How Much Energy is Used by Cellular Communications Now?**

According to [6]–[8] , the annual carbon footprint of a mobile subscriber was 25kg from 2007 - 2011, or roughly equivalent to running a 5W lamp for a year - including the supply chain, vendor, usage and end-of-life phases in the life cycle of the handset. A further breakdown of the carbon footprint by Mike Berners-Lee [9], updated this figure in June of 2010 with a breakdown that included the transmission of calls accounting for 47kg per year - of which 23.1kg is allocated to the base station - and only 3.2kg to phone energy. Unfortunately, it appears costs of communications on the provider side is one of the most guarded secrets in the industry so it is difficult to obtain more modern figures. Phones and base stations have improved their energy efficiency, but more energy is likely used overall - because we use our phones way more than we did back then (in terms of minutes per day). We also request much more data than ever before - this would significantly increase the energy costs on the back end side of the network (both in terms of “switchboard” and “admin” costs from Berners-Lee’s original breakdown).

There have also been other efforts [10] to determine how much energy is used across countries, and even the entire planet. One of the key conclusions from the report in [10] was that at the time, energy consumption was independent of traffic load. In other words, devices and equipment were using the same amount of energy whether they were being used or not.By necessity however, mobile phones have largely tackled this problem in order to achieve longer periods of time between charge. This makes using them as routers ideal from an energy efficiency perspective. According to [11], at time of publication there were 8.2 billion mobile connections (including m2m). Assuming the 25kg carbon footprint from [6] [7] [8], that’s 205 billion kg (or 205Mt) annually of greenhouse gases or 1/4 of Canada’s greenhouse gas emissions annually [12]. Using the updated numbers from Mike Berners-Lee, the number jumps to 385Mt annually. This is almost half of the Canada’s emissions. In terms of energy - assuming the 5W lamp for a year, we get 5W x 24 hours x 365 days = 43.8 kWh per phone x 8.2 billion phones, or 359 terawatt hours (TWh) per year. The smallest nuclear power plant in the USA, the Fort Calhoun plant generates 4.2 TWh per year assuming it runs nonstop, so this is the equivalent of 85 of these power plants [13] - just to power today’s world mobile phone communications network. For comparison, back in 2012, it was estimated that worldwide, communications networks by 2015 would require 350TWh [14]. Currently, there are 449 nuclear reactors operating in the world [15], with a generating capacity of 2467 TWh [16]. Mobile communications networks represents about 15% of our current nuclear generating capacity.

**How Much Energy May Be Saved by Adopting a Mobile Mesh?**

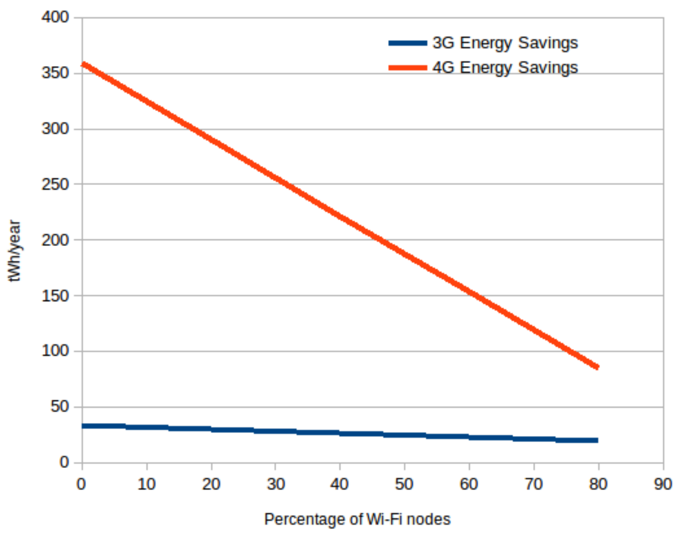
If it is assumed that mobile mesh is adopted by everyone, the biggest challenge is reducing the amount of traffic to the Internet to save energy. There are two ways this can be accomplished. First, is with applications which are really peer-to-peer (p2p). These are things like messaging, file transfers and other interactions with other people directly nearby on the mesh. Things where all of the popular solutions use infrastructure but may not need to - for instance, if two people want to send a Facebook message, or a Slack message - the message goes from from the first person to the the mobile phone network, to the Internet, to an AWS server, back to the Internet, to another mobile phone network, to the second person's phone. What if the two people are sitting in the same room? An immense amount of energy by just sending it directly over Wi-Fi or Bluetooth. According to Huang et. al,[17] , LTE uses 23 times more energy than Wi-Fi and 3G uses 10.8 times more. There is a much more complicated picture including which one uses more during idle, transmit etc. - but this could be examined in much more detail. This is just the first-hop energy saved. Some work has been done in this area using a single hop (non-mesh case by offloading between Wi-Fi and LTE in a HetNet) by Zhou et al [18]. If the Internet transmission is also avoided, all of the energy in the network switches along every hop of the way, and data centre costs to process and store the message can also be reduced. In the IoT space, if we consider that in places like the home, all of the IoT devices people will interact with will likely be close to them, and the phone is part of the same mesh, we can significantly reduce the amount of data flowing to the Internet if it is able to reach the phone through the mesh. Alternatively, one device in the home, such as the Wi-Fi router could act as a data aggregation node while only one or two IoT devices remain directly connected to it, while other Iot devices connect to the router, through other IoT devices. On a wider scale, image this same logic applied across neighbourhoods, cities and even out in large scale environmental sensing deployments.

The second way in which energy can be saved is by caching data that many users are accessing, or multicasting it to many users - the objective is to reduce the number of requests that go directly to the Internet. For instance, consider a large sporting event where many people would like to watch, listen to, or obtain data such as stats and scores - such as the Olympics. In this case, the device which is sharing its Internet connection would be the only one required to request it from the Internet, and then anyone else who also requests the same content could either receive the packets directly from the Internet connected device or by joining the stream in progress by joining the multicast group. In this survey paper, [19] , There is a multicasting approach which also adjusts the power of nodes in the mesh at the same time, which was found to reduce the power by 75% below the best known alternative technique. This is on top of the already lowered power by avoiding all of the Internet transmissions. This can be applied to IoT devices for cases when firmware or software on the devices are updated. All of the devices in an entire deployment may be updated with a relatively low energy cost compared to sending the update to each device one at a time.

If we further consider that an intelligent network can select the device(s) which are closest to the cellular tower as the ones which shares their Internet connection, energy can further be reduced. The cellular tower and the cellular phone (or IoT device) transmits at the lowest power with the closest device. Instead of transmitting at high power to farther devices, all of the traffic is routed at lower power through the close device, and then hops along using lower powered Wi-Fi, BT and other low energy technology. More theoretical results backing this are given by

Fedro et. al [20]. As devices which are acting as gateway devices to the Internet run low on energy, the next two nearest devices can take their place and so forth extending the life of the IoT network.

If we assume that the 5W energy consumption is applied to a device using a 4G / LTE network all of the time, and then use the 23 times more energy used compared with Wi-Fi and consider 3G using 10.8 times more than Wi-Fi, it is possible to graph the energy savings by converting some of the proportion of the nodes to Wi-Fi nodes and relaying through them to the cellular network. In the figure below, there is a difference of 14.1 TWh per year saved between having no Wi-Fi offloading and 80% offloading. The savings when looking at 4G networks is much greater. Doing the same comparison between no Wi-Fi offloading and 80%, there is a difference of 274 TWh per year saved worldwide.




If we zoom back in to some typical IoT deployments, let’s assume a network of 50 IoT devices, perhaps in some type of home of the future. Let’s also assume this home does not have a dedicated internet connection, because it’s located in India and a cellular connection is what everyone uses. This device would use say 5W, and one of the other devices also has a cellular connection so it also uses 5W. If every device in this person’s home also used cellular connections, this would be 50 * 5W = 250W total or 43.8kWh * 50 = 2190kWh per year which is more than most fridges. Further, if every home starts to have this many devices, the cellular networks will not be able to handle this many connections at once to the network. If instead only two devices act as gateways, we get 5W + 5W + (48 * 0.22W) = 20.43W or 175.2kWh - ie) less than 1/10 of the energy usage. Of course the real number would be higher because there is some extra usage to forward packets on behalf of other devices, but even if it is doubled or tripled it is still much less overall than it would be using a direct connection.

So the solution to connecting all of the things without using all of the power is to ensure that not every IoT device is directly connected to the Internet. This can be accomplished using ad hoc networking, mobile mesh networks and forwarding through the IoT devices themselves. By using the devices to form the mesh, deploying the network becomes much easier than having to also install infrastructure to support the network. Combining this with techniques such as caching, multicast and data aggregation will only multiply the energy savings and further increase the efficiency of IoT networks.

**References**


[1] C. Hoffman, “Think Twice About Getting a Microcell (or T-Mobile CellSpot) if You Live in an Urban Area,” *How-To Geek*, 17-Nov-2015. [Online]. Available: https://www.howtogeek.com/233660/dont-get-a-microcell-or-t-mobile-cellspot-if-you-live-in-an-urban-area/. [Accessed: 03-Aug-2017].

[2] E. Geier, “All about beamforming, the faster Wi-Fi you didn’t know you needed,” *TechHive*, 08-Nov-2013. [Online]. Available: https://www.techhive.com/article/2061907/home-networking/all-about-beamforming-the-faster-wi-fi-you-didnt-know-you-needed.html. [Accessed: 03-Aug-2017].

[3] C. Frompovich, “Will 5G Be Cost Effective For The Cell Industry?,” *Activist Post*, 22-Jul-2017. [Online]. Available: http://www.activistpost.com/2017/07/will-5g-cost-effective-cell-industry.html. [Accessed: 03-Aug-2017].

[4] S. Archer, “UBS: The super-fast next generation cell phone service only makes sense for the wealthy (T, VZ, S, TMUS),” *markets.businessinsider.com*, 20-Jul-2017. [Online]. Available: http://markets.businessinsider.com/news/stocks/5g-cell-phone-service-only-makes-sense-for-the-wealthy-2017-7-1002192329. [Accessed: 03-Aug-2017].

[5] gbaconqz, “The plans for 5G to power the internet of things,” *Quartz*, 21-Feb-2014. [Online]. Available: https://qz.com/179980/the-plans-for-5g-to-power-the-internet-of-things/. [Accessed: 03-Aug-2017].

[6] M. S. Obaidat, A. Anpalagan, and I. Woungang, *Handbook of Green Information and Communication Systems*. Academic Press, 2012.

[7] E. H. Ong, K. Mahata, and J. Y. Khan, “Energy Efficient Architecture for Green Handsets in Next Generation IP-Based Wireless Networks,” in *2011 IEEE International Conference on Communications (ICC)*, 2011.

[8] A. B. Ericsson, “Sustainable energy use in mobile communications,” *white paper, EAB-07: 02l80l Uen Rev C*, 2007.

[9] M. Berners-Lee, “What’s the carbon footprint of ... using a mobile phone?,” *The Guardian*, 09-Jun-2010.

[10] G. Auer *et al.*, “How much energy is needed to run a wireless network?,” *IEEE Wirel. Commun.*, vol. 18, no. 5, pp. 40–49, Oct. 2011.

[11] G. Intelligence, “GSMA Intelligence.” [Online]. Available: https://www.gsmaintelligence.com/. [Accessed: 03-Aug-2017].

[12] “Environment and Climate Change Canada - Environmental Indicators - Greenhouse Gas Emissions,” 09-Jan-2007. [Online]. Available: https://www.ec.gc.ca/indicateurs-indicators/?lang=en&n=FBF8455E-1. [Accessed: 03-Aug-2017].

[13] "How much electricity does a nuclear power plant generate? - FAQ - U.S. Energy Information Administration (EIA)." [Online]. Available: https://www.eia.gov/tools/faqs/faq.cfm?id=104&t=3. [Accessed: 03-Aug-2017].

[14] S. Lambert, W. Van Heddeghem, W. Vereecken, B. Lannoo, D. Colle, and M. Pickavet, "Worldwide electricity consumption of communication networks," *Opt. Express*, vol. 20, no. 26, pp. B513–24, Dec. 2012.

[15] "World Statistics - Nuclear Energy Institute." [Online]. Available: https://www.nei.org/Knowledge-Center/Nuclear-Statistics/World-Statistics. [Accessed: 03-Aug-2017].

[16] Wikipedia contributors, "Nuclear power by country," *Wikipedia, The Free Encyclopedia*, 25-Jul-2017. [Online]. Available: https://en.wikipedia.org/w/index.php?title=Nuclear_power_by_country&oldid=792315270. [Accessed: 03-Aug-2017].

[17] J. Huang, F. Qian, A. Gerber, Z. M. Mao, S. Sen, and O. Spatscheck, "A Close Examination of Performance and Power Characteristics of 4G LTE Networks," in *Proceedings of the 10th International Conference on Mobile Systems, Applications, and Services*, Low Wood Bay, Lake District, UK, 2012, pp. 225–238.

[18] F. Zhou, L. Feng, P. Yu, and W. Li, "Energy-efficiency driven load balancing strategy in LTE-WiFi interworking heterogeneous networks," in *2015 IEEE Wireless Communications and Networking Conference Workshops (WCNCW)*, 2015, pp. 276–281.

[19] S. Brienza, S. E. Cebeci, S. S. Masoumzadeh, H. Hlavacs, Ö. Özkasap, and G. Anastasi, "A Survey on Energy Efficiency in P2P Systems: File Distribution, Content Streaming, and Epidemics," *ACM Comput. Surv.*, vol. 48, no. 3, pp. 36:1–36:37, Dec. 2015.

[20] S. Fedor and M. Collier, "On the Problem of Energy Efficiency of Multi-Hop vs One-Hop Routing in Wireless Sensor Networks," in *Advanced Information Networking and Applications Workshops, 2007, AINAW '07. 21st International Conference on*, 2007, vol. 2, pp. 380–385.