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WEARABLES WHITE PAPER

During the last years, we have witnessed the appearance of smart watches, fitness/activity trackers and many other small devices attached to/embedded in our clothes and accessories. These devices are known as wearables. Wearables are Internet of Things (IoT) devices designed for personal use. Coming in various shapes and forms, wearable devices are equipped with mini computers and sensors/actuator to gather information, process, display and communicate data either directly through embedded cellular connectivity or through another device.

The growth of the wearables market in the last few years is impressive. In 2015, 78.1 million wearable devices were shipped worldwide[1]. In 2017, the forecasts predicted the shipment of 96 million[2] up to 113.2 million[3] wearables while the market is still in the early phases of expansion. Ericsson's report reveals that smartphones may become the 'second screen' or even be replaced by wearables in the future[4]. By 2021, analysts forecast wearable device shipments to surpass 185 million pieces and the value of $16.9 billion, with watches and wristbands driving volume while clothing and hearables gain traction.

As the graphic reflects, fitness, activity & sport trackers are one of the most successful market segment for wearables. According to the analysis from the International Data Corporation (IDC) Worldwide Quarterly Wearable Device Tracker[5], basic wristbands (fitness bands) are the most popular wearables to date with 40% market share. However, they are quickly expected to become a commodity and lose share in the course of the forecast. By 2021 smartwatches are expected to experience the strongest rise in the wearables market share followed by sensor-laden clothing (e.g. smart shoes) and earwear (e.g. wireless headphones with additional features such as fitness tracking or audio augmentation).

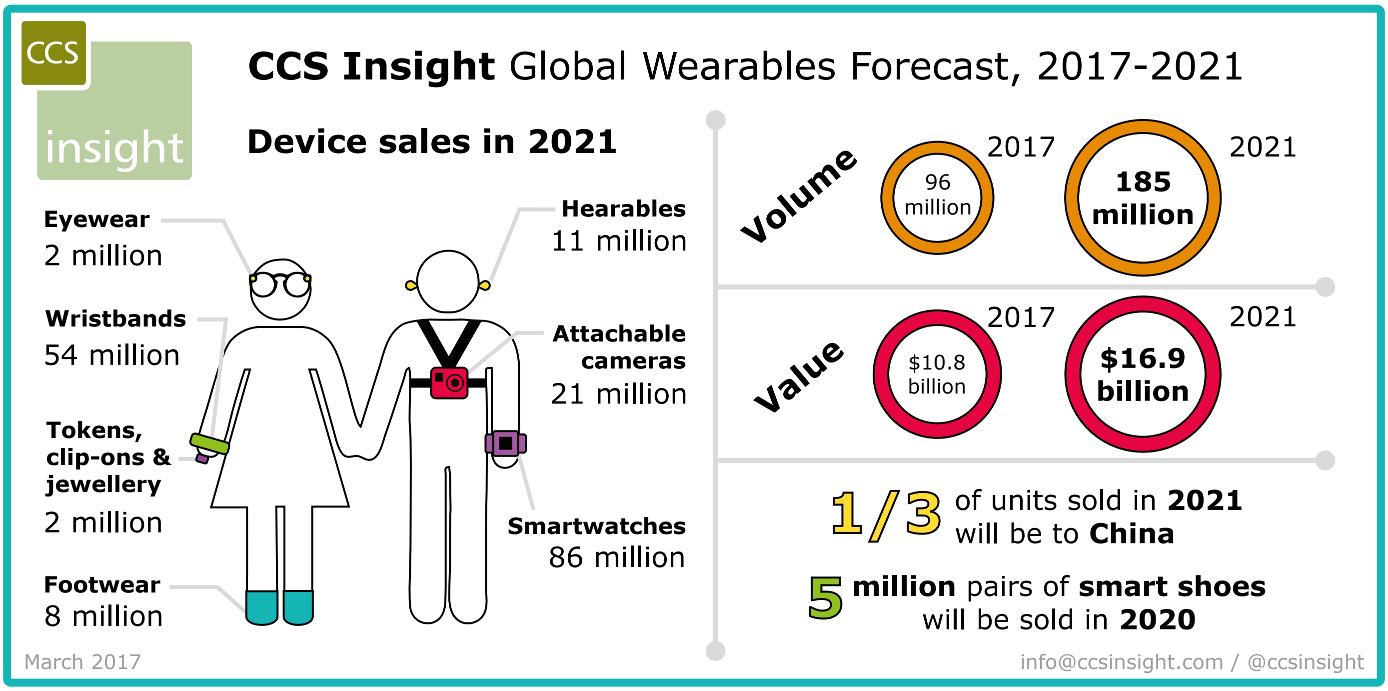

Figure 1: The global forecast of number of wearable devices from CCS Insight

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[1] *IDC Worldwide Quarterly Wearable Device Tracker, February 23, 2016*

[2] *CCS insight, "Global Wearables Forecast", March 2017*

[3] *IDC Worldwide Quarterly Wearable Device Tracker, December 20, 2017*

[4] *Ericsson Consumer Lab, Wearable technology and the Internet of Things, 2016*

[5] *https://www.idc.com/getdoc.jsp?containerId=prUS43408517*

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These numbers are a clear consequence of the growing enthusiasm for fitness and health, which is shown in the statistics from some countries in the last years. Over 58 million Americans paid gym membership fees in 2017[6], with the actual visits to the gyms exceeding 5 billion per year. Moreover, the number of memberships has grown 27% between 2008 and 2017. In China, an industry report shows that the total number of gym attendees in 70 major Chinese cities has increased by four to five million each year since 2011[7].

Healthcare is another area where wearables may have a major impact. The healthcare wearables are expected to improve the quality of life in ways that impact medical conditions, improve diagnosis and care, and ultimately save lives. These devices are expected especially for chronic medical conditions such as cancer, heart conditions and diabetes. In the case of diabetes, the number of diabetic patients among Americans is 29.1 million (9.3% of the population), which is increased number compared to year 2010[8]. Nevertheless, the global market for remote patient monitoring system is projected to reach US$46 billion by 2020[9]. Other estimations[10] forecast that, the global Internet of Things (IoT) healthcare market is estimated to grow from USD 32.4 billion in 2015 to USD 163.2 billion by 2020.

These quantity of wearables will also have a tangible impact on mobile traffic. Wearables communication needs are mostly related to sending sensors' data to the server and receiving notifications or content from it. Some more advance wearables as VR headsets or body-worn cameras also need high throughput links to stream or receive media content. CISCO Virtual Network Index (VNI) predicts that globally, traffic from wearables will grow 23-fold from 2015 to 2020[11].

WHY 3GGP AND WEARABLES ARE A GOOD MATCH?

With the rise of wearable technology, it becomes increasingly important to just 'get it right'. End users these days have high expectations from their devices and their demands vary on what they use the wearable for. It is to be expected that end users exploiting wearables for professional purposes, such as in a public safety or medical context will have different demands than consumers that use a wearable for monitoring sport activities. So, in order for device manufacturers to create truly attractive devices, they will have to take these expectations into account. Depending on the use case, the following expectations on wearables are to be fulfilled:

- Wearables should function independent from the smartphone, i.e. be more than a smartphone accessory. Accordingly, data usage of wearables can be charged independently from mobile phones.
- Wearables should provide an always on / always online experience.
- Data from wearables should be adequately privacy protected and secured.
- Batteries of wearables should be long lasting.
- Easy to manage and maintain.
- They should be easy to use and have an appealing design for an affordable price.
- Wearables should be small enough to be worn.

Today, wearables are often connected using short range radio technologies like Bluetooth and WiFi Direct in order to save power and achieve a small size (form factor). Wearables are not often associated with 3GPP technology, even though 3GPP capabilities in wearables could help to fulfill the end-user expectations. In the sequel, it is explained how 3GPP technology could help to fulfil these expectations without losing the benefits of a small form factor and long battery life.

In order to save battery power, manufacturers until now preferred short range radio technologies over LTE in the wearables. This makes sense from a historical perspective as originally LTE was intended for delivery of high data rates. Nowadays, the 3GPP ecosystem evolved and also includes NarrowBand Internet of Things (NB-IoT) and LTE Machine type of communication (LTE-M), which are optimized for low power operation (long battery life) and reduced complexity. These recent additions to the ecosystem, therefore pave the way for the usage of cellular modems in wearables due to decrease in antenna size and reduced costs. Here with, the major reasons for not using 3GPP technology for wearables has disappeared. In addition, wearables can benefit from the latest developments in 3GPP technology. One reason to include 3GPP technology in a wearable is that it provides true standalone capabilities. For example, wearables are often paired with the smartphone using a short range radio technology and share their data with e.g. an App on the phone. This limits the standalone functionality of the wearable because without the paired smartphone nearby the wearables wouldn't have connectivity. Besides, if the smartphone is nearby the wearable may not be able to use it because the corresponding App is not installed, the versions are incompatible or software is outdated. In such cases, the wearable often loses functionality. However, if a wearable is equipped with a 3GPP chipset, it could function as a standalone device.

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[6] https://www.statisticbrain.com/gym-membership-statistics/

[7] http://www.chinadaily.com.cn/business/2015-07/29/content_21441675.htm

[8] http://www.diabetes.org/diabetes-basics/statistics/?loc=db-slabnav

[9] http://www.strategyr.com/MarketResearch/Remote_Patient_Monitoring_Systems_Market_Trends.asp

[10] http://www.marketsandmarkets.com/Market-Reports/iot-healthcare-market-160082804.html

[11] Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2015–2020.

This is especially relevant in the situations in which a smartphone is inconvenient or too inefficient to be used e.g. people practicing sports or housekeeping as well as when wearables are used for manufacturing in a factory or in a medical treatment.

Another advantage of the standalone capabilities of a 3GPP enabled wearable is that it allows the wearable to provide an always on (always online) experience. Using 3GPP technology, a wearable can attach to the cellular network and thereby benefit from all the services that 3GPP networks provide. Amongst others, LTE/LTE-M networks natively provide mobility support and roaming, service continuity and guaranteed QoS. Roaming and mobility support facilitate the same user experience for indoor and outdoor environments as well as when the user is travelling with the device. Service continuity and QoS make sure that 3GPP enabled wearables become suitable for multimedia and public safety use cases.

Another reason to use 3GPP technology in wearables is the fact that it simplifies device management and improves its security. Every device that connects to a 3GPP network is equipped with an Universal Subscriber Identity Module (USIM) that stores credentials for accessing the network. These credentials are used by the operator to authenticate the device, enable encryption for data exchange between the device and the network, and to manage the devices. Accordingly, 3GPP enabled wearables become a part of a well-established ecosystem with these built-in features.

All listed benefits, however, can only be obtained if the technology that is currently specified by 3GPP meets the requirements for various wearable use cases. The next chapter therefore addresses the optimized forms of LTE, namely NB-IoT and LTE-M, and explains how these technologies are suited for battery constraint devices.

WHAT DOES 3GPP ALREADY OFFER FOR THE WEARABLE WORLD?

One characterizing aspect of a wearable is its small form factor that dictates the use of extremely small batteries. Because of this, it becomes a challenge to develop (optimize) wearables such that they provide uninterrupted services for a long period of time on a single battery charge. Small form factor puts additional challenges on the electromagnetic compatibility (EMC) issue for device makers, considering that multiple wireless communications should be supported for some popular services, like Near Field Communication (NFC) for payment, Bluetooth/WiFi for smartphone and LTE for cellular connection. Deploying multiple antennas in the tiny space allowed by a typical wearable form factor is also a challenge. In fact, the wearable may actually be too small for even two antennas, which poses a limit on the possible communication interfaces of wearables. Furthermore, the small form factor limits the size of a wearable device's power amplifier (PA), and also limits the thermal engineering opportunities to control the temperature of the PA. Because of these effects, wearable devices may be severely disadvantaged in RF capability compared to smartphones. In order to address these needs, 3GPP has developed NB-IoT and LTE-M that are battery and cost efficient.

Over the last years, LTE is expanded with radio technologies specifically designed for low throughput, low cost and low battery drain. In the context of wearables, two specific LTE-based technologies are worth mentioning, namely NB-IoT and LTE-M. These are promising technologies for wearables, particularly the lower-capability wearable devices that do not require high data rates nor dense duty cycles, but that may have extreme requirements on long battery life and also provide coverage extension methods that can help compensate for RF limitations of a wearable device. Furthermore protocol support is introduced for efficient communication of small amounts of data between a device and the network. The benefits of LTE are increasing over time as number of 4G mobile connections is currently greater than for its 3G and 2G counterparts[12] and 4G coverage and speed are still growing.

The adoption of the listed advances in LTE technology results in a battery life. For wearables, the small form factor prescribes the use of small batteries. In some cases e.g., tracking devices there is no option to recharge the battery and the life-time of the device is determined by the battery life. Many of these wearables will only send limited amounts of data, such as a tracking device that is programmed to report its geographic coordinates on e.g., per hour basis. This implies that such wearables will benefit from the recently introduced NB-IoT and LTE-M without losing the benefits that wearables already have.

One should not consider wearables as a single class of devices. In fact, there are multiple types of wearables. Up to the present, most commercial wearable devices were limited capability devices i.e. generating minimum radio traffic or at most supporting some basic user applications such as voice/Email. However, the possible scope of wearable devices is much larger with the future products that could become important in the marketplace encompassing mission critical communications (body sensors and medical devices), high data rate with low latency (VR and gaming), low activity machine type communications (trackers), as well as the existing service classes. These needs have to be met while still complying with the form factor restrictions to make a device truly wearable, meaning that the battery life will remain critical and the radio functionality will remain challenging. In line with this, different types of wearables should be equipped with distinct types of radio

[12] *https://opensignal.com/reports-data/global/data-2016-11/report.pdf*

chips. Whereas for some wearables NB-IoT is the best option, an LTE-M or even a regular LTE chip is a better choice for others e.g., the ones that occasionally require higher bandwidths. The choice of the proper 3GPP technology will depend on the given wearable and the related use case. This is another benefit of using 3GPP technology that could handle a variety of use cases with a single network.

Another aspect of wearables is communication to a companion device, which often is a smartphone. Such a link, which is called a sidelink (SL) can support local communication between the wearables and portables as well as support wearable-network communication by smartphone relaying. On the one hand, this is an advantage because present-day wearables are usually in close proximity of smart phones and often move together with smartphones. In this fashion the short-range connection between the wearable and phone allows for energy-efficient communication. On the other hand, when there is no sidelink connection available or the SL connection cannot meet the communication requirements, the wearables should be able to connect to the infrastructure network directly. However, the inclusion of both a sidelink and a direct link communication channel complicates the hardware and software design of the wearable device, which is one of the drivers to also develop a 3GPP based sidelink and facilitate relaying that is elaborated on in the next chapter.

The design requirements for the sidelink and direct link are different. For the direct link communication, the requirement on low power consumption is much more stringent for wearable devices than for smartphones. For the sidelink communication, scalability and ability to operate in high dense scenarios are important requirements. Table 1 categorizes various types of wearable devices considering communication requirements, device capability and device physical constraints. The type 1 devices prerequisites are low power consumption (long battery life), low device cost and small form factor. Type 3 devices provide services beyond what is supported in typical smart phones e.g., AR/VR and remote medical treatment posing stringent requirements on latency, reliability and data rates compared to other two device types.

Feature\Type	**Type 1**	**Type 2**	**Type 3**
Data rate	<=250Kbps	[1, 10] Mbps	[100,500] Mbps
Latency	~1s	10~100ms	5ms
Lifetime	Months or years	Months	Weeks
Reliability	~ 99%	99% ~ 99.99%	99% ~ 99.99%
Modem cost	Cost sensitive, <1 US$	Cost sensitive, 1 ~5 US$	Cost insensitive,
Battery	Coin cell	Coin cell, small rechargeable battery	Small rechargeable battery
Radio access type & communication range	Long-range cellular radio access and short range sidelink radio access	Long-range cellular link and short-range side link	Long-range cellular link and short-range side link
Mobility	Group mobility together with connected phone; limited standalone mobility as NB-IoT does not support handover	Group mobility together with connected phone; standalone mobility as normal UE	Group mobility together with connected phone; standalone mobility as normal UE
Form factor	Very limited	Limited	Limited or as normal UE
Typical applications	Fitness sensor, sport monitoring, position tracking, Smart band	Smart watch	Glasses, AR/VR, remote medical treatment

Table 1: Wearable devices classification

Requirements of various device types described in Table 1 could be met by various LTE versions. Depending on the performance, bandwidth (throughput), mobility complexity and power usage aspects one of the LTE versions described in the sequel could be deployed.

LTE Advanced is technique that provides highest throughputs and allows for mobility and low latency – the requirements specified for Type 3 devices. These high performance features affect the system design i.e. larger bandwidths (n x 20MHz) , multiple antennas, power consumption etc. Consequently, complexity, battery usage and size increase leading to a form factor similar to usual handheld devices (smartphones).

LTE-M is an evolution of LTE optimized for machine type of communication standardized in 3GPP. Both LTE transmission techniques i.e. frequency division duplexing (FDD) and time-division duplexing (TDD) are supported by LTE-M. Using the typical LTE subframe structure of 1ms low latency can be achieved. Transceiver design is simplified as it exploits solely the smallest LTE carrier i.e. 1.4MHz band (some LTE-M versions preserve the ability to operate in LTE bands up to 20MHz). LTE-M is multiplexed over a full 1.4MHz LTE carrier and can therefore transmit fairly large chunks of data (~1Mbps). It is a suitable technique for applications such as wearables, tracking objects, energy management, utility metering, and city infrastructure. An extended coverage range can be achieved using LTE-M. Depending on the selected LTE-M version it is applicable for the lower end of Type 2 devices as well as for Type 1 devices specified in Table 1.

NB-IoT is specifically developed for ultra-low end of machine type of communication corresponding to the Type 1 devices specified in Table 1. NB-IoT uses a system bandwidth of only 200kHz resulting in a simplified transceiver design. The 200kHz bands can flexibly be deployed in e.g., an LTE guard band, within a normal LTE carrier or as a standalone carrier. NB-IoT devices possess power saving feature and have an extended coverage. NB-IoT can support more than 200000 subscribers per cell.

The advantage of LTE-M and NB-IoT communications is that they can operate using the normal construct of LTE networks. By a software upgrade most of the existing base stations can be upgraded to support these communication types.

WHAT IS STILL TO COME IN 3GPP

3GPP recently started to consider wearables as a distinct device class. p to the present they were recognized as a peripheral tethered to a conventional wireless device. Incorporating wearable devices into standardized cellular ecosystems requires a new view on the wearables as full 'members' of the ecosystem with their own capabilities, identities, and constraints. In this chapter the wearable related challenges in 3GPP standardization as well as insights in the upcoming developments are described.

RELAYING AND MUTIHOP FOR WEARABLES

Relaying of wearable device traffic through a smartphone is addressed in 3GPP as part of the LTE-Advanced Pro development effort. The motivation for adding relaying capabilities to LTE is to reduce the power consumption of wearables and improve the coverage of the network.

One of the options being considered in 3GPP is to design a Layer 2 relay that introduces advantages of relaying without losing a direct connection for the wearable application. From the perspective of the wearable application, the connection does not change whether in direct mode (wearable and eNB directly connected), indirect mode (wearable and eNB connected via a relay) or even when changing between indirect mode and direct mode. This approach therefore allows a wearable device to use a low-power, short-range radio link towards the relay, while the more power-intensive cellular link (relay-eNB) is operated by the less battery-constrained smartphone.

The impact of such an approach to the 3GPP standards is nontrivial and encompasses diverse technical areas such as the Layer 2 protocols, QoS management, bearer architecture in the core network, etc., to achieve the basic functionality of relaying service for the wearable devices in a way that integrates naturally into the 3GPP ecosystem while making the wearable device visible as a separate entity to the core network. Further enhancements to allow optimized battery performance, intelligent use of QoS to deliver optimal service quality in a diversity of services and radio environments are foreseen and will have their own impact on 3GPP standard.

Multihop relaying is another topic discussed in 3GPP. It refers to relaying over multiple nodes aiming to reduce the power consumption of battery limited nodes as well as to increase the network coverage.

PROXIMITY SERVICES (PROSE)

Proximity Services (ProSe) is also one of the 3GPP developments. ProSe is a generic technology meant for smartphones and wearables alike. ProSe enables 3GPP compatible devices to communicate to each other directly. Wearables and smartphones that are ProSe enabled will therefore be able to connect with each other using 3GPP technology. ProSe facilitates device pairing process where devices identify each other using their 3GPP credentials. This mechanism is more secure compared to other short range techniques. Using 3GPP technology also for proximity services eliminates the need for multiple radio chips by wearables.

SECURE PAIRING

One of the challenges wearables experience is - how to securely pair them? Wearable might have a very limited or no user interface at all, whereas the owner would still like to control who can access/use the device and for what purpose. With the technology that is still to come, mobile operators could play a vital role in the field of secure pairing. The fact that a device contains operator controlled credentials means that there is a trust anchor embedded in it. For wearables, smart phones or other devices containing these trust anchors the operator can provide necessary key material to enable access management and their secure pairing.

SECURITY

At present, when tethering is used, the relaying device can intercept and modify the data exchanged between the wearable and the mobile network.
To secure such a link a complicated over the top security mechanism needs to be applied between the wearable and some application server on the internet.
Alternatively, an App on the relaying device might provide some sort of 'store and forward' mechanism which is equally complicated an undesirable from a security point of view.

With the newly proposed 3GPP Layer 2 relaying technology, the wearable retains the advantages of a direct connection even when the communication is relayed. With this technology the link between the remote UE and the mobile network can be protected using 3GPP methods. The user plane terminates in the UE and the eNB in such a way that existing mechanisms can readily be reused for protecting this link between the wearable and the network.

Data protection is of increased importance in scenarios related to health monitoring. Wearables used for health monitoring show a clear case of why support is needed for devices that are used temporarily only. Examples could include wearables that are used to collect information about quality of sleep, heart rate monitors, changes in blood pressure, for a multi-day period. These wearables will typically be owned by a health service provider. However, the mobile phones that these devices should use as relays, can be owned by the patients or their family members. It is of clear benefit if these kind of wearables can use any mobile phone without a tedious 'pairing'. However, the mobile phone and wearables may have credentials from different operators. Therefore, mobile operators will have to ensure that business arrangement for this kind of 'roaming' are in place.

SYNCHRONIZATION OF DEVICES

Synchronization of devices would be mandatory for many use cases. For example, future AR/VR glasses will often be combined with other wearables in a body area network or with video game controllers. In these cases, different media streams may go to different devices, e.g. a video stream goes to the AR glasses, whilst an audio stream goes to a headset. These media streams could be coordinated via a central gateway device for the body area network. An example scenario would be that the smartphone receives all streams and then sends the audio stream to a headset and the video stream to a screen; however, for high bandwidth streams the phone could easily become the bottleneck, which is why it may be better to have direct links to the network for example for both the AR glasses and the audio headset.

In these cases, a sidelink between the wearable devices can be used to coordinate the different media streams (e.g. for synchronisation or media control). From the user perspective, it would be beneficial if multiple wearables from different device vendors can work together in a body area network. This would require additional standardisation on e.g. service discovery of wearables. Also operator provided services (e.g. voice and video telephony) would benefit from standardised interfaces between different types of wearables in a body area network.

CONCLUSION

The wearable market continues to grow and to mature. And while doing so, the nature of wearables connectivity will change. Already with today's 3GPP technology, there are clear benefits to equip a wearable with a cellular chip; these benefits include long battery lifetime, always-on / always online experience, better manageability, increased security, and standalone behaviour. In the future, there will be even more compelling reasons to include a cellular capabilities in a wearable.
It will provide a wide range of optimized services for specific types of wearables without losing the benefits of present-day 3GPP technology. To sum up, anyone working on wearables should seriously consider joining 3GPP and the 3GPP ecosystem.

This white paper evolved within the Wearable Special Interest Group (SIG) and is co-signed by:

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