5G Carrier Grade Wi-Fi: Requirements and Technologies

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1 Introduction

Wi-Fi accounts for 40% of all data delivery in present wireless systems, which is 20 times greater than data delivery over cellular systems [1]. Overall, Wi-Fi wireless data delivery is expected to increase exponentially through 2017, much of which is attributed to expanding deployment. Public Wi-Fi locations are growing rapidly (see Figure 1) and adding to existing Wi-Fi dominance for indoor home and enterprise use.

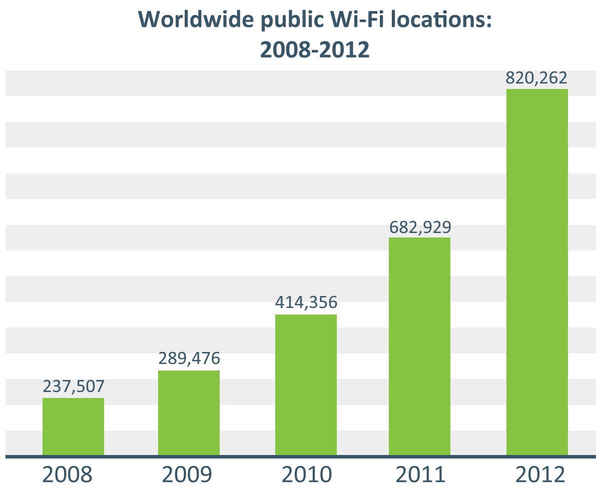

Figure 1: Growth in Public Wi-Fi locations

This paper gives an overview of InterDigital's 5G Carrier Grade Wi-Fi (5G-CGW) vision for addressing the expanding Wi-Fi usage. CGW is a term used to describe the future direction of 802.11 requirements and performance objectives. 5G-CGW exhibits the following characteristics which are further described in Figure 2:

- Higher air-interface efficiency to support large number of users
- Stable "cellular-like" quality
- Support for robust and dynamic deployments (e.g. dense deployments and flash crowds)

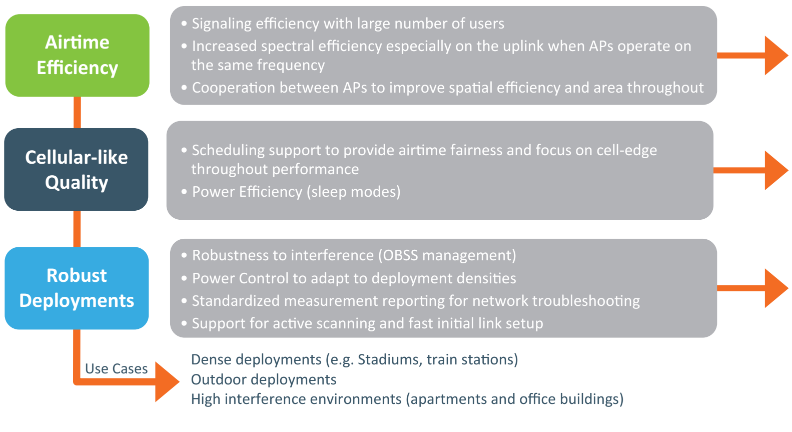

Figure 2: 5G Carrier-Grade Wi-Fi (CGW) Requirements

1.1 Wi-Fi Standards

The recently ratified Wi-Fi technology, 802.11ac, is foreseen as being inadequate to address the needs of 5G-CGW requirements. Though 802.11ac added several enhancements to improve per user MAC throughput and optimize peak throughput, it does not fully address the requirements noted above for a 5G-Carrier Grade Wi-Fi experience. Among the deficiencies of 802.11ac are [2, 3, 4, 5]:

- Inadequate utilization of RRM
- Not optimized for dense AP and STA deployments
- Lack of Inter-AP coordination
- Lack of support for multiple uplink transmissions.

To address these deficiencies the WLAN standards community has introduced a new study group, High Efficiency Wi-Fi (HEW), which has been described as the next significant technology development area for 802.11. The most prominent motivation for HEW is to address the deficiencies noted above for 802.11ac [6]. The anticipated throughput for this technology is 10 Gbps, a tenfold improvement over 802.11ac.

1.1.1 Standards Technology Evolution

The stated goal of the 802.11ac specification was to deliver 500 Mbps for a single user link and 1 Gbps for a multi-user link. These goals have been met through a combination of an increase in spatial degrees of freedom, higher modulation modes and support for increased bandwidth, both contiguous and non-contiguous. A comparison of recent releases of the 802.11 specifications, as well as anticipated requirements for HEW, is given in Figure 3. HEW is currently engaged in writing the Project Authorization Request (PAR) for a new Task Group which will tackle the requirements of Carrier Grade Wi-Fi.

Feature	802.11n(2005)	802.11ac(2008)	HEW(~2014)
MIMO Antennas	4	8	8
Channel Bandwidth	20 and 40 MHz	20,40,80+80 MHz BW's	>160 MHz likely
MAC Channel Bonding	Limited functionality	Enhanced Protection Methods	Extension to Mulitple Parallel Channels Possible
MAC Channel Access Methods	One AP/STA per TXOP	One AP shared with Multiple STAs	Possible multiple APs and STAs
Multi-User MIMO	Not Supported	Optional for downlink	Potential likely for uplink
Spatial Streams (SS)	1-4 SS (2SS Mandatory for AP)	1-8 SS (>1 SS Optional)	1-8 SS (>2 SS possible)
Modulation	BPSK,QPSK,16QAM, 64QAM	11n, plus 256 QAM (Optional)	256 QAM possibly mandatory
Frequency Band	2.4GHZ, 5GHz	5GHz	2.4GHz, 5GHz

Figure 3: Comparison of recent 802.11 Specifications

2 Landscape and Market Requirements

2.1 Growth of Mobile Data Traffic

The growth rate of new-device mobile data traffic is two to five times greater than the growth rate of users. Globally, mobile data traffic will grow 13-fold from 2012 to 2017, a compound annual growth rate of 66% [1]. Cellular technologies may not be able to keep pace, and Wi-Fi solutions for additional cellular traffic offload will likely continue.

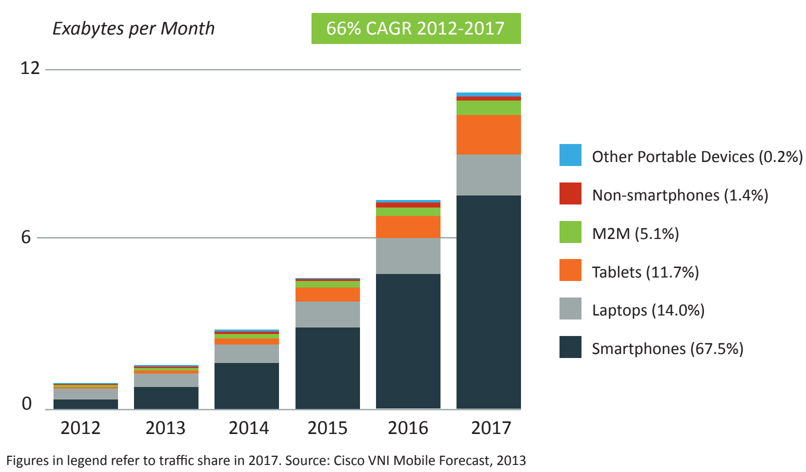

Figure 4: Global Traffic forecast by Device

It has been reported that mobile data traffic may reach the following milestones in the near future [1, 8]:

- The average mobile connection speed will surpass 1 Mbps by 2014
- Tablets will exceed 10 percent of global mobile data traffic by 2015
- Monthly global mobile data traffic to peak at 21 exabytes by 2017
- Due to increased mobility of users, wireless data traffic will drive the increase of mobile data traffic
- Monthly mobile tablet traffic will surpass 1 exabyte per month in 2017

In addition it has also been reported that almost all subscribers who have both cellular and Wi-Fi in their devices use Wi-Fi. According to Cisco's VNI estimates, Wi-Fi accounted for 33% of mobile traffic from cellular devices in 2012. Wi-Fi traffic from mobile devices continues to provide mobile operators valuable relief from congestion [9].

As a percentage of 2012 device levels, the percentage growth for several dominant device types are shown in Figure 5 below.

2.2 Mobile Application Trends

With the significant growth of smartphones and tablets, it may be anticipated that for these device types wireless traffic may be dominated by web browsing, and video transfer. These traffic types demand very high peak throughput, and very high area throughput for the dense cell usage scenarios anticipated by the HEW study group [6]. It has also been noted that the use consumers make of Wi-Fi is different from their normal mobile use of the same smartphones. This may be a reflection of: (1) the greater speed of Wi-Fi, and (2) price sensitivity to mobile data plans that are tiered or have usage caps. Mobidia data show that YouTube and downloads are far more common at home than when using the macro cellular network [10].

Device Type	Growth in Devices, 2012-2017 CAGR	Growth in Mobile Data Traffic, 2012-2017 CAGR
Smartphone	20%	81%
Tablet	46%	113%
Laptop	11%	31%
M2M	36%	89%

Figure 5: Growth in Device Mobile Data Traffic

Rank	Cellular	Wi-Fi	Roaming
1	Browsing	Browsing	Browsing
2	Facebook app	YouTube	Facebook app
3	Tethering	Video and audio streaming	Google Maps
4	YouTube	Downloads	E-mail
5	Downloads	iPlayer	Tethering

Source: Informa/Mobidia (2012)

Figure 6: Device Traffic types

3 Technical Overview

3.1 Requirements of 5G-CGW

While the past few evolutions of 802.11 have focused on improving the throughput at the link layer, it is now apparent that future improvements will also require changes that will emphasize new metrics. For instance, "area throughput" measured in bits/sec/m^2 can better reflect the performance of dense Wi-Fi deployments which will be required for 5G-CGW. Other requirements being discussed in the IEEE 802 HEW study group are:

- Improved performance in real world deployments, both indoor and outdoor. These include the following scenarios:
    - Dense deployments of APs and STAs
    - Heavily loaded BSSs
    - Interference from adjacent BSSs
- Improved user experience and quality of service
- Reduced overheads, leading to improved spectral efficiency

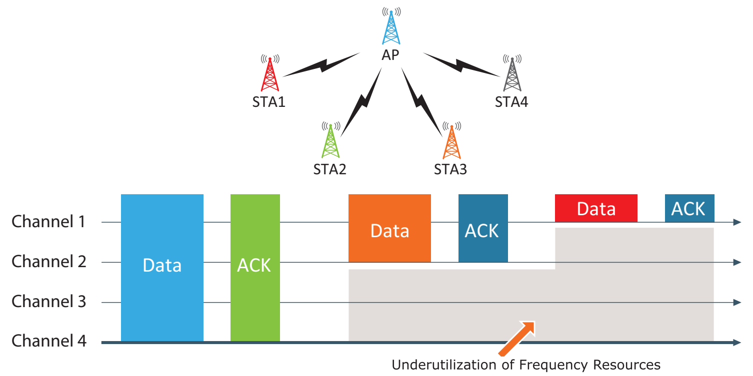

Figure 7: Inefficient Frequency Resource Utilization

3.2 Candidate technologies for 5G-CGW

The 802.11ac specification has already exploited the dimensions of frequency and space by specifying larger bandwidths and multiple antennae. In this section we will briefly introduce some new technology directions that are envisioned for 5G-CGW.

3.2.1 Multi-user Parallel Channel Access (MU/PCA)

One of the principal requirements of new amendments to 802.11 has been backward compatibility with past amendments. Hence 802.11ac is backward compatible to 802.11n and 802.11a. Since 802.11ac has a mandatory bandwidth of 80 MHz while 802.11n and 802.11a are 40 MHz and 20 MHz wide respectively, backward compatibility is maintained by allowing an 80 MHz capable AP to transmit to only one narrower band STA at a time on a primary channel. This leads, inevitably, to underutilization of the frequency resources as shown in Figure 7.

Multi User Parallel Channel Access (MU/PCA) schemes that are backward compatible with the existing CSMA/CA but also allow multiple users to transmit simultaneously in parallel frequency sub-channels can significantly improve throughput. Figure 8 shows the throughput improvement that can be achieved when an 80 MHz capable AP transmits to four 20 MHz STA's simultaneously for different packet sizes. Significant throughput gains of 250% - 300% have been shown to be possible using such schemes [11].

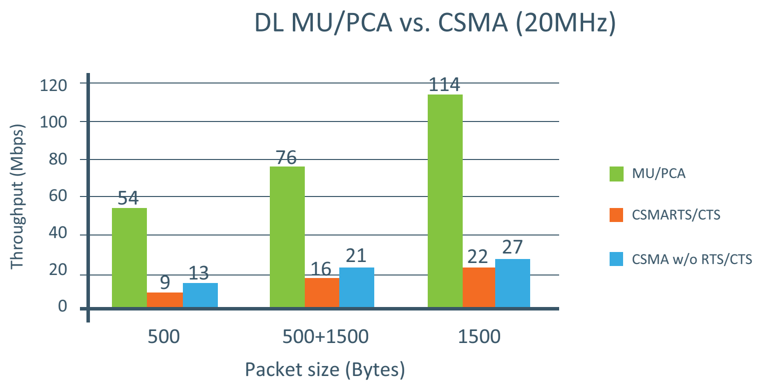

Figure 8: Efficient use of parallel frequency channels can provide 2x to 3x throughput improvement

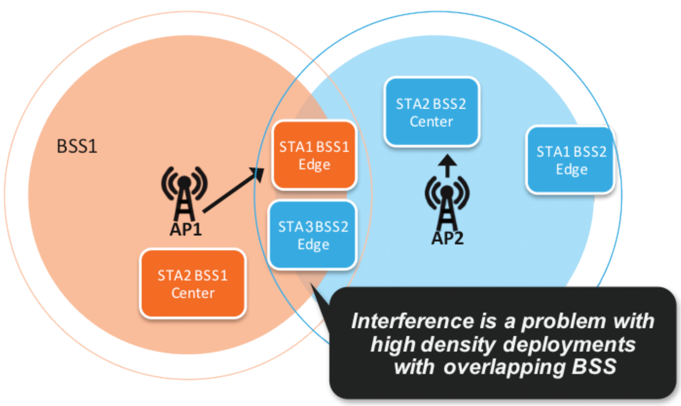

Figure 9: Overlapping BSS transmissions

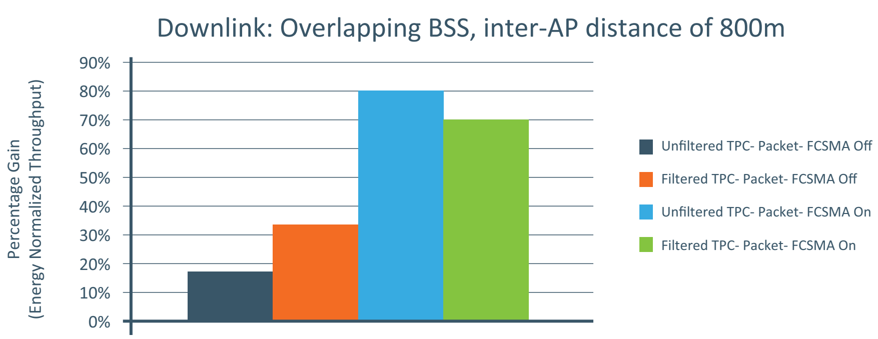

Figure 10: Downlink throughput gains with FCSMA and TPC

3.2.2 Fractional CSMA (FCSMA) and Transmit Power Control (TPC)

One of the deployment scenarios of interest to 5G-CGW is dense deployments of APs. This, inevitably, leads to Overlapping Basic Service Sets (OBSSs). When available, adjacent APs in OBSSs may choose different frequency bands of operation, but in some cases this may not be possible. When multiple OBSSs use the same frequency bands, interference becomes a problem especially for STAs on the edge of coverage. The increased interference results in a reduction in the network throughput as seen at the MAC layer and an increase in energy expenditure. The effect of transmission in OBSSs is illustrated in Figure 9 in which AP1 and AP2 independently transmit data to STAs in their BSSs simultaneously. The transmission from AP1 to {STA1, BSS1} (shown in brown) may fail due to the transmission from AP2 to {STA3, BSS2} (shown in blue).

With appropriate TPC mechanisms and inter-BSS coordination, it is possible for the two APs to transmit simultaneously with few or no collisions. One such mechanism is a fractional CSMA/CA scheme in which only a fraction of the total STAs are permitted to access the channel at a specific time. The access duration is coordinated between multiple BSSs to limit the amount of interference experienced. TPC is incorporated to ensure that the interference resulting from the coordinated transmissions is limited. The technique implicitly reduces the coverage of a subset of the BSSs in the network, reducing the amount of overlap and hence improving the system performance. Figure 10 shows the downlink performance improvement that may be achieved using these methods. Similar improvements of approximately 80% to 100% in throughput are observed on the uplink as well [12].

3.2.3 Uplink Multi-User MIMO (UL MU-MIMO)

The 802.11ac specification introduced for the first time in 802.11 the concept of transmitting to multiple users at the same time within the CSMA/CA MAC using Multi-User MIMO (MU-MIMO).

However, this was only restricted to one-way transmissions, that is, multiple transmissions from a single AP to multiple STAs or downlink MU-MIMO. This allows increased throughput on the downlink. However, the uplink throughput did not increase. With UL MU-MIMO, multiple STAs (with fewer number of antennae) can simultaneously transmit to an AP with a larger number of antennae, e.g., 4 single-antenna STAs transmitting to an AP equipped with 4 antennae. With increasing volumes of user-generated data being uploaded to social networking sites, increasing the uplink throughput would significantly improve the user experience. Additionally, most of the complexity would reside at the AP [13].

Some of the technical challenges of implementing UL MU-MIMO are:

- Synchronizing uplink users in frequency and time to enable coherent decoding at the AP
- Grouping of users such that the capacity is maximized
- Power control to ensure proper AGC operation at the AP

These challenges can be overcome with appropriate system designs and algorithms, which are currently being developed and tested.

4 Conclusions and Next Steps

Carrier Grade Wi-Fi is widely seen in the industry as being the next generation enhancement to Wi-Fi and will drive the requirements in the HEW study group. The technologies described in this paper can address the need for increased uplink throughput, dense deployments, and cellular-like quality. InterDigital's team has brought to bear years of experience with Wi-Fi technology to develop innovative solutions that can achieve 4 to 6 times the capacity of IEEE 802.11ac with cellular-like quality. Our 5G-CGW technology has been widely published in journals and discussed at industry events [11-15]. As 5G-CGW moves towards reality, InterDigital looks forward to collaborating with industry and university partners to transition the technology from concepts, to reference platforms, and to deployed products.

5 References

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