Quantum Advances in Wireless

Gain ICs

QUANTUM ADVANCES

A succinct figure of merit for overall efficiencies in wireless transmission is the ratio of carrier frequency to bitrate. In that regard, an exciting new breakthrough in wireless communication developed by Gain ICs, instantaneous wireless (IW), comes in at 2 cycles/bit with 2 constellations in contrast to the fastest bitrates currently achievable, using Quadrature Amplitude Modulation (QAM) with 256 constellations (IEEE 802.11ac), at 57 cycles/bit and ASK, used in simpler applications where software demodulation is not practicable, like RFID, comes in at a substantially worse 180,000 cycles/bit. The closer to 1 the better, where IW improves wireless transmission 28 times over QAM and 90,000 times over Amplitude Shift Keying (ASK) by this measure. These efficiencies enable quantum advances, significantly improving wireless communication depicted in Figure 1. They also enable creation of entirely new wireless applications.

SALIENT INNOVTION

Quadrature architectures, and in particular 256 quadrature amplitude modulation (QAM), are ubiquitous in contemporary radio frequency (RF) transmissions. They require down conversion to an intermediate frequency (IF) or direct conversion to base frequencies directly (zero IF). In either case, channel noise, like frequency aliasing from down conversion and I/Q synchronization, effectively double noise over Gaussian noise, while also shrinking signal space to increase throughput with higher constellation sizes. Both increased noise and decreased signal space severely degrade transmission, requiring increased power and expense to ameliorate these deficiencies.

Software defined radios (SDR), while attempting to avoid the notorious limitations of quadrature and down conversion, introduce even more impediments to communication in other ways. A huge limitation is the Nyquist sample frequency, sample frequency being at least twice as fast as the inverse of the smallest deviation, effectively pushing carrier to very low frequency. This attenuates range and requires very wide bandwidth to increase bitrates to acceptable levels, albeit still well below those of quadrature modulation. In turn, this spread spectrum solution is hampered by frequency-dependent effects like attenuation and absorption.

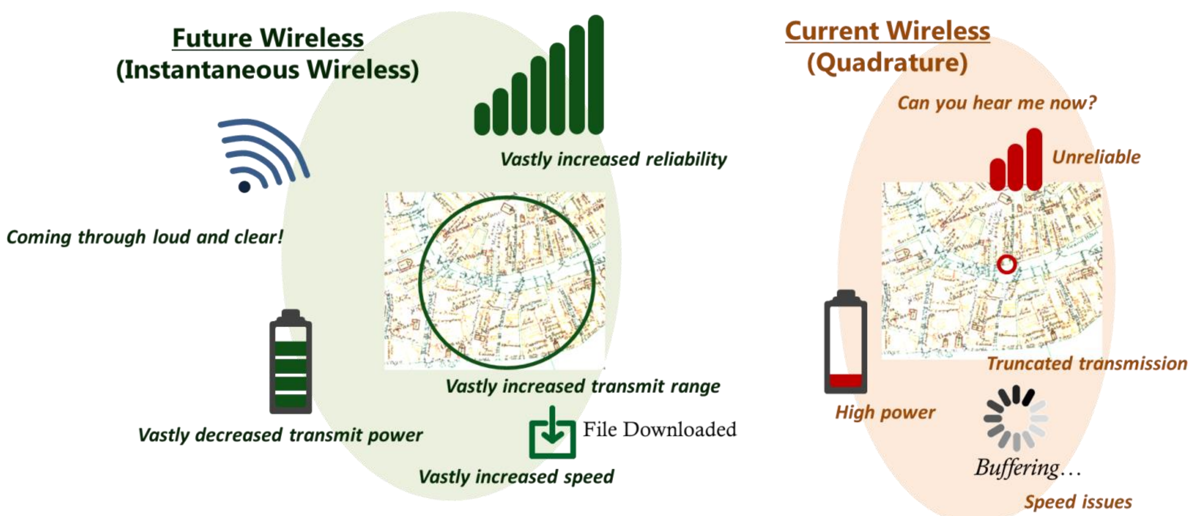

Figure 1. IW improves existing wireless applications and enables entirely new ones.

The lower SDR carrier frequencies and wider bandwidth also results in another detrimental conflict: the required signal energy needs to be kept low to avoid contention with other signals across wide spectra, while it also needs to be kept high to avoid blackouts. Compromises to such conflicts limit speed, congest frequency spectrum, and lead to less reliability than quadrature. In contrast, IW eliminates these tradeoffs, optimizing both speed and efficient spectrum utilization.

The ideal modulation of IW, ultra-phase modulation (UPM), allows breakthrough advances over existing standards, seen in Figure 2. The limitations of existing methods are eliminated: no down conversion (neither direct or IF) of quadrature and no oversampling issues as with SDR. Reception is simplified to essential operations only: amplify, filter and demodulate. This reduced receiver noise and increased signal space over quadrature solutions and avoidance of sampling limitations like those of SDR allow IW to transmit farther with higher reliability (at essentially zero bit error rate), at higher throughput, with less average bit energy, and with greater link spectral efficiency, surpassing quadrature and SDR in all key performance metrics.

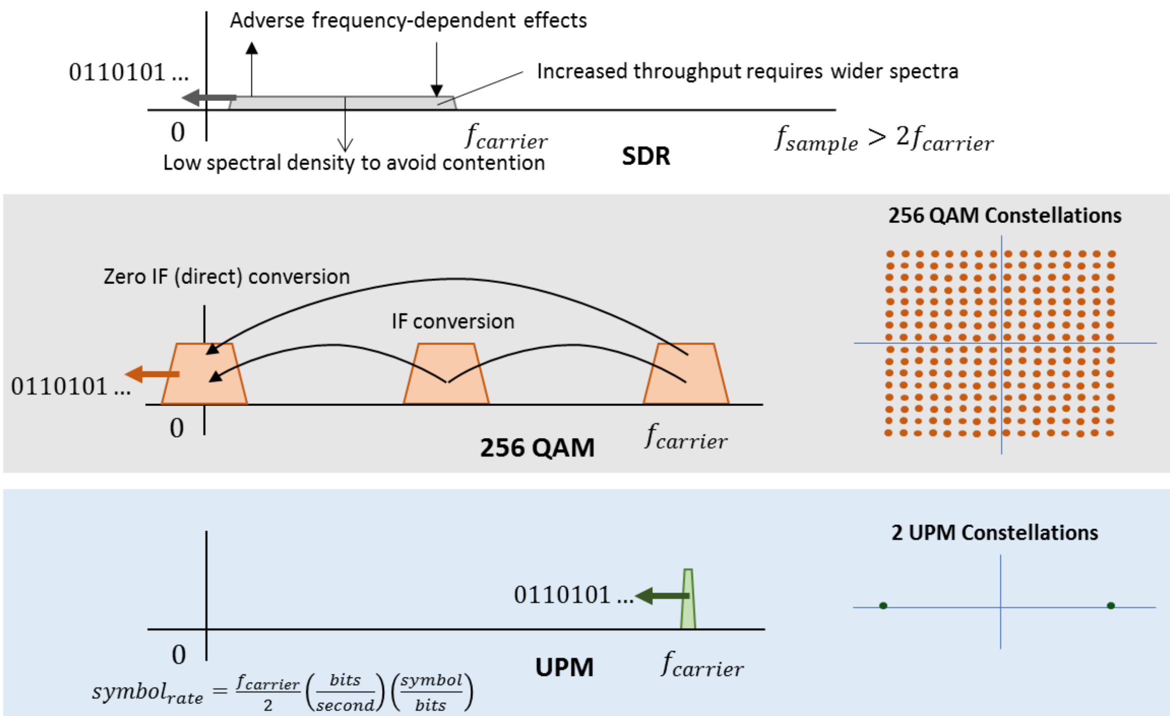

Figure 2. Simplify RF reception to filter, amplify and demodulate only via UPM.

The simplicity of IW, using UPM, is reflected in increased efficiencies across all performance metrics, as typical in the power amplification needed to achieve adequate transmit power, usually the dominant system power, seen in Figure 3. The UPM's demodulation at the carrier frequency and 128 times reduction in constellation complexity offers multiple orders of magnitude better noise immunity than 256 QAM, while also avoiding several noise introduction mechanisms such as the filters and mixers of the conventional approach. Because the signal constellation now consists of only equal-amplitude points as shown in Figure 2, the peak to average power ratio (PAPR) of the signal is 0 dB, compared to 8 to10 dB of a typical 5G signal. Now, the power amplifier (PA) operates only at a fixed amplitude, which is the most efficient operating mode, requiring only constant-envelope operation, and incurring no PAE penalty. In contrast, a 10-dB PAPR typically corresponds to a 2 to 5 times reduction in average transmit efficiency unless complicated efficiency enhancement strategies are employed; these usually require additional digital linearization techniques, another complexity that UPM avoids.

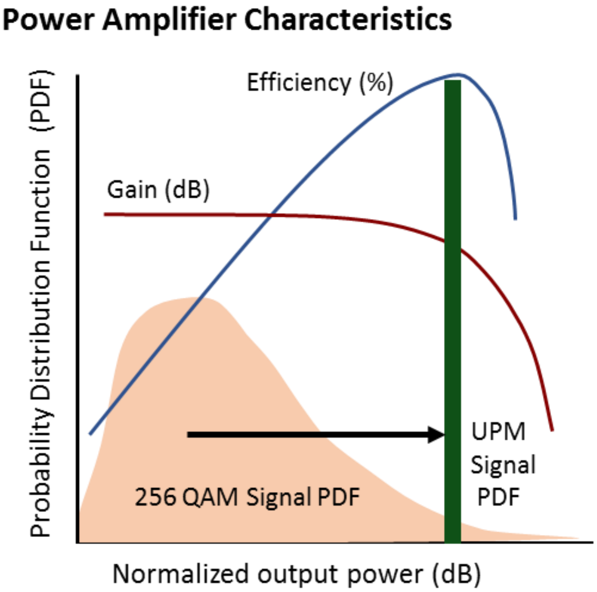

Figure 3. UPM efficiencies in transmit power.

A contrast of the simplicity of UPM relative to 256 QAM and a summary of performance gains is in Figure 4.

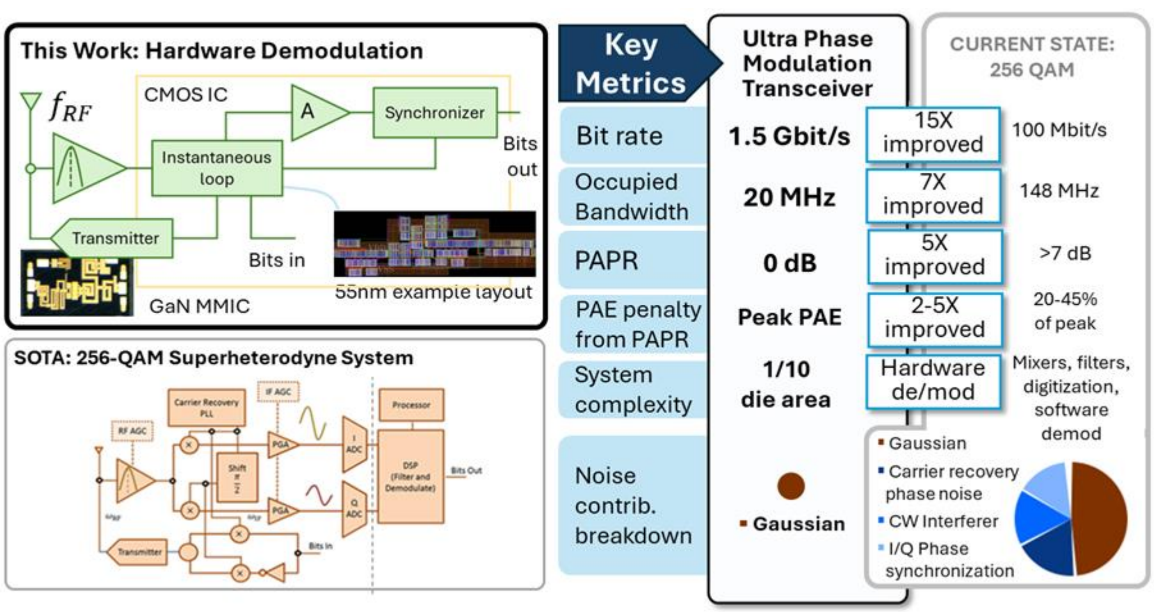

Figure 4. Contrast between IW and 256 QAM.

SALIENT ADVANCES

The breakthrough efficiencies of IW allow it to potentially supplant wireless communication across a wide range of applications. Three instances, Fixed Wireless, WiFi and item-level tagging, demonstrate such disruptive advances in RF communication. Other IW advances to wireless communication demonstrate how a wide range of RF applications can be enhanced.

Fixed Wireless, Range and Reliability

Fixed wireless is especially hampered by the truncated range and compromised reliability of QAM. The higher QAM throughput from 256 constellations comes at the high cost of substantially reduced transmission ranges and degraded BER, translating into increased re-transmissions, requiring added expense like increased power and beamforming to counter such losses. Channel noise for 256 QAM, for instance, is double the device and supply noise which ideally should be dominant in determining reliability and range. IW overcomes this dilemma with 2 fast constellations, optimally wide signal space, and by reducing receiver noise to device and induced supply noise only.

The receiver sensitivity of IW, owing to wide signal-space from optimal 2 constellations and low noise, is at 10^{-33} joules shown in Figure 5 relative to 256 QAM at 10^{-11} joules. Sensitivity is not limited architecturally. Inherent limitations with QAM architecture can be observed as roll-off curves are far from the inherent limit of a physical noise floor. A physical noise floor, comprised of noise sources such as black body, cosmic noise and atmospheric noise, is typically -100 dBm around 3 GHz, roughly 10^{-13} joules translates to Eb of 10^{-35} joules. The efficiencies of IW are denoted by this proximity to the physical noise floor.

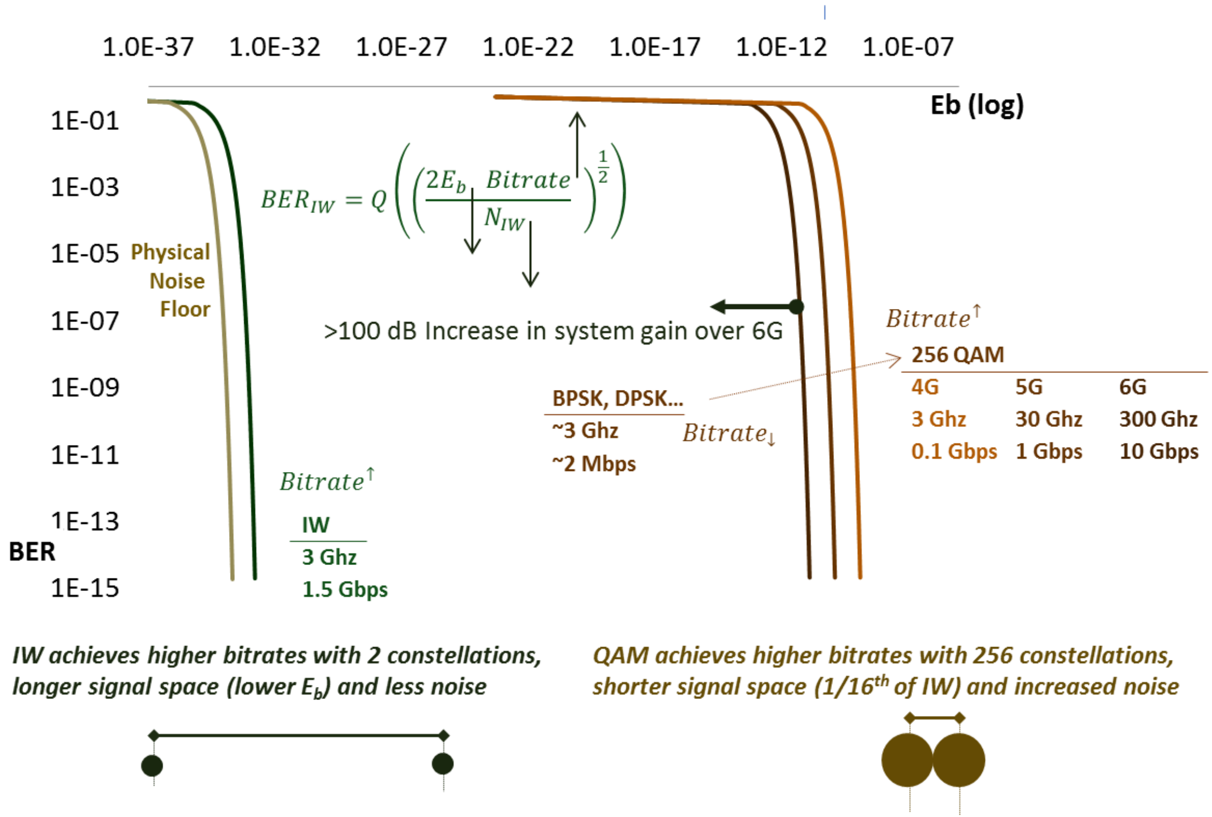

Figure 5. Receiver sensitivity of IW relative to QAM.

Increased sensitivity can be also be seen by increasing modulation amplitude in Figure 6. As modulation deviation increases receiver sensitivity decreases as expected. Average bit energy and modulation deviation can be set to remain well above physical noise floor while still keeping sensitivity orders of magnitude below QAM. Ideally, around 10^{-20} joules would provide a 100 dB increase in system gain while providing orders of magnitude increase in range and reliability.

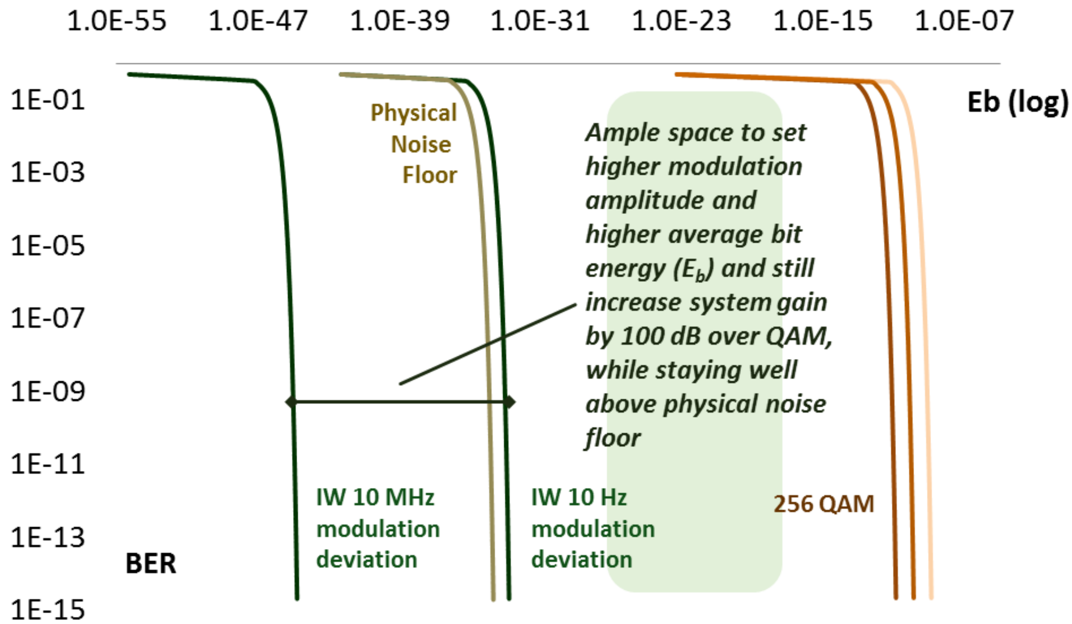

Figure 6. Setting receiver sensitivity via average bit energy and modulation amplitude.

These increases in system gain from IW translate into substantially greater range and reliability. Transmit range, in the minimum, increases with IW by a factor of 1,000 over 256 QAM, in Figure 7. Given the donut radiation pattern relative to isotropic, range is still limited by spherical spreading and free-space loss. In practice, increased transmit power, beamforming and phased array antennas, as well as substantially reduced bitrates, are used to extend the range to adequate distances. QAM especially, partly to compensate for the architecturally truncated ranges, implements a host of possible to boost range. For instance, Mobile LTE 4G, using 256 QAM at 3 GHz, is limited to 5 Mb/s downloads speeds, and 1 Mb/s upload speeds, optimized, along with excess power and beamforming, to reach 400 to 1,600 meters. IW, by contrast, reaches 18 kilometers without increasing power and without increasing power, decreasing bitrates and without beamforming.

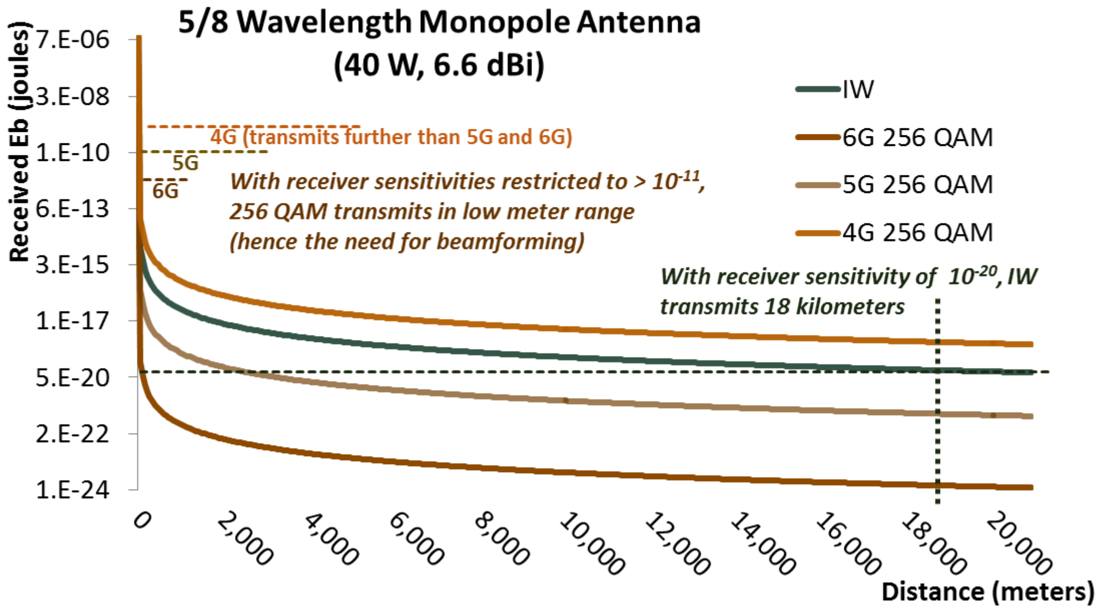

Figure 7. Range and reliability of IW relative to QAM

Decreasing throughput to 1 Mb/s, increasing power by factor of 12, where FCC effective radiated power per channel is limited to 500 W, and implementing simple beamforming to increase antenna gain by from 2 dB to 5 dB, range can be seen to increase. Transmit distance increases by a factor of more than 100 for 5 dB increase in gain in Figure 8, still not within the desired range from 400 meters to 1,600 meters. The higher frequencies realize even less increase in range.

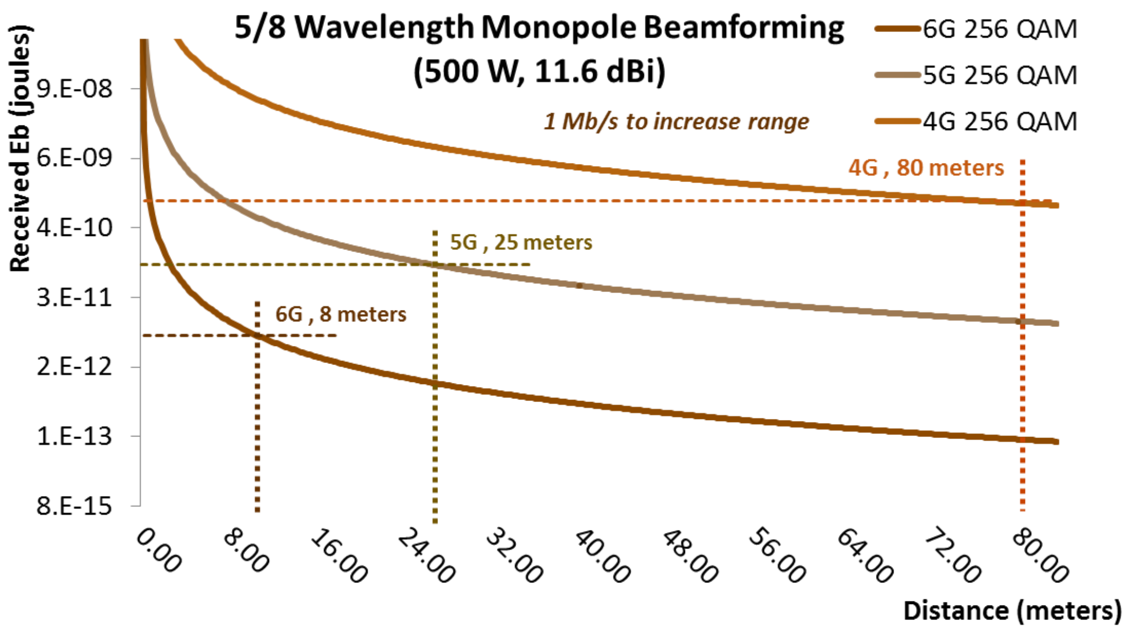

Figure 8. Farther range from increased power, lower throughput and simple beamforming.

Utilizing phased array antennas, as typically done on cellular towers, gain is boosted high enough to achieve the desired longer distances in Figure 9. Using a collinear array with 300 elements demonstrates how 4G falls within the desired range of 400 meters to 1,600 meters, at 736 meters, a 1,000 time increase in distance for 4G. Again, higher frequencies reach far less gains in range in 5G and 6G.

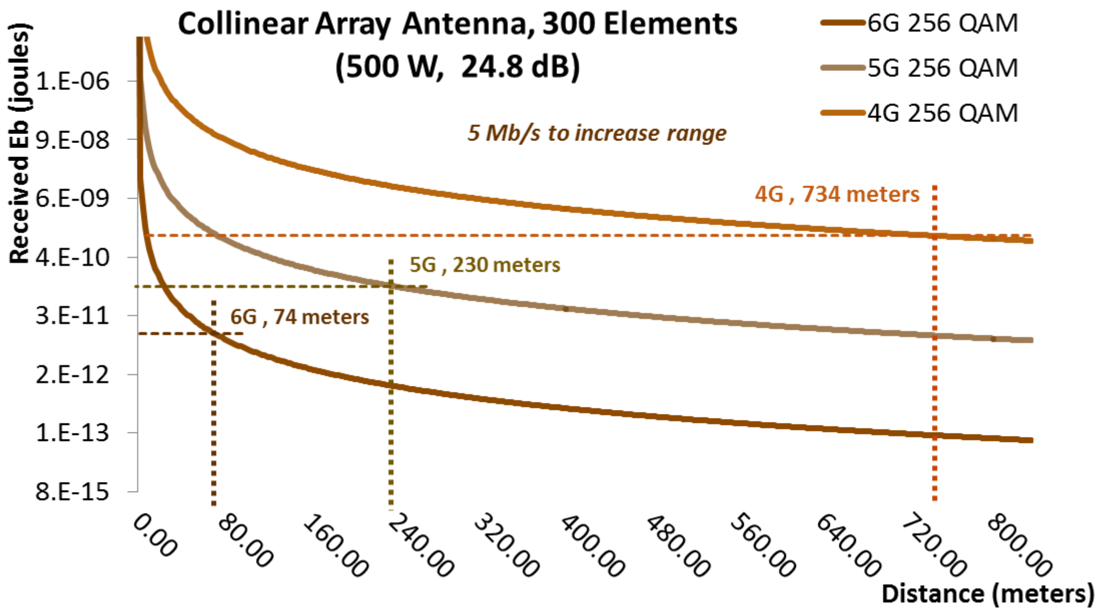

Figure 9. Collinear Arrays on cellular towers increase antenna gain to achieve desired ranges.

With bitrates 300 times higher, power 12 times lower, and without resorting to beamforming, IW still transmits 25 times farther than a 256 QAM link implemented with all these range enhancing measures. Without those enhancements, IW transmits 18,000 times farther at the same transmit power and 4,000 times farther at 1/10th the transmit power. IW reliability is also higher given larger margins on the waterfall curves. These advances are a huge boon to fixed wireless transmission.

Capacity, Spectral Efficiencies

Inherent high throughput and minimal noise of IW result in greater spectral efficiency. Two constellations with less noise, Gaussian noise only versus pronounced channel noise of quadrature, versus many constellations required to achieve high throughput in quadrature, result in substantially high link spectral efficiency (LSE).

Figure 10 shows this spectra corresponding to average bit energies of frequency shift keying (FSK), 256 QAM and IW. Quadrature average bit energy to overcome much higher noise and larger constellation size, in the case of QAM, necessarily are set at higher per their higher sensitivities, at roughly -40 dBm to -60 dBm. The greater spectral efficiency of IW regardless of modulation magnitude is evident, even at more than double the bitrate. At almost 5 times wider spectra, traditional FSK is considered to be wideband solution.

IW, being 2 clock cycles of carrier clock per bit, inherently high bitrate, spends one of those clock cycles essentially at the carrier frequency and the second clock cycle either faster or slower per modulation. Hence the bulk of the energy focuses at the carrier to reduce width of the occupied bandwidth by orders of magnitude over traditional FSK and still narrowing the width more than 256 QAM.

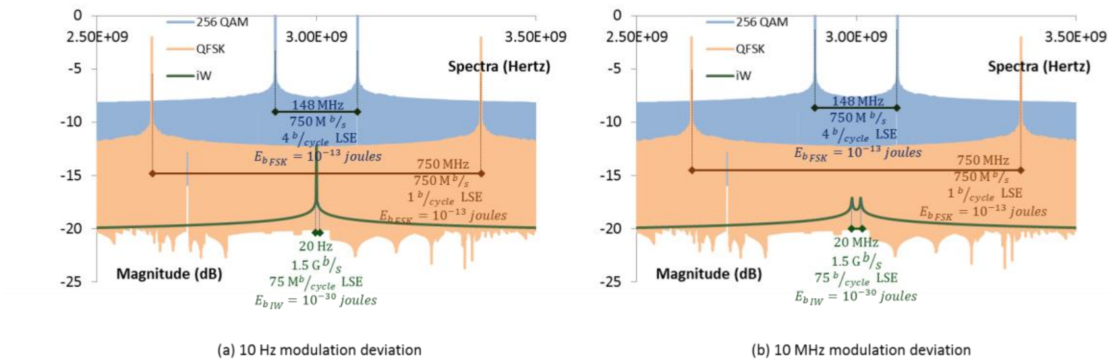

Figure 10. Vast increase in spectral efficiency regardless of modulation amplitude.

Currently, WiFi grapples with the limitations of QAM, especially from increased noise to achieve needed throughput and the resulting relatively large spectra per channel. The substantially greater LSE of IW eliminates these limitations. Low capacity, a key dilemma with WiFi networks, is no longer an issue.

In-flight WiFi for entertainment in the aerospace industry is illustrative of this. Current efforts are pursuing a solution, albeit expense limits installations to about half of the aircraft only. Only about 22 passengers with can be accommodated with WiFi service. Calculations with the QAM communications they are using show that only about 18 passengers could watch standard-definition movies simultaneously, allowing 30% more time above communication for multiplexing overhead, as demonstrated in Figure 11. With IW, capacity is no longer an issue and simplicity reduces implementation costs to increase feasibility.

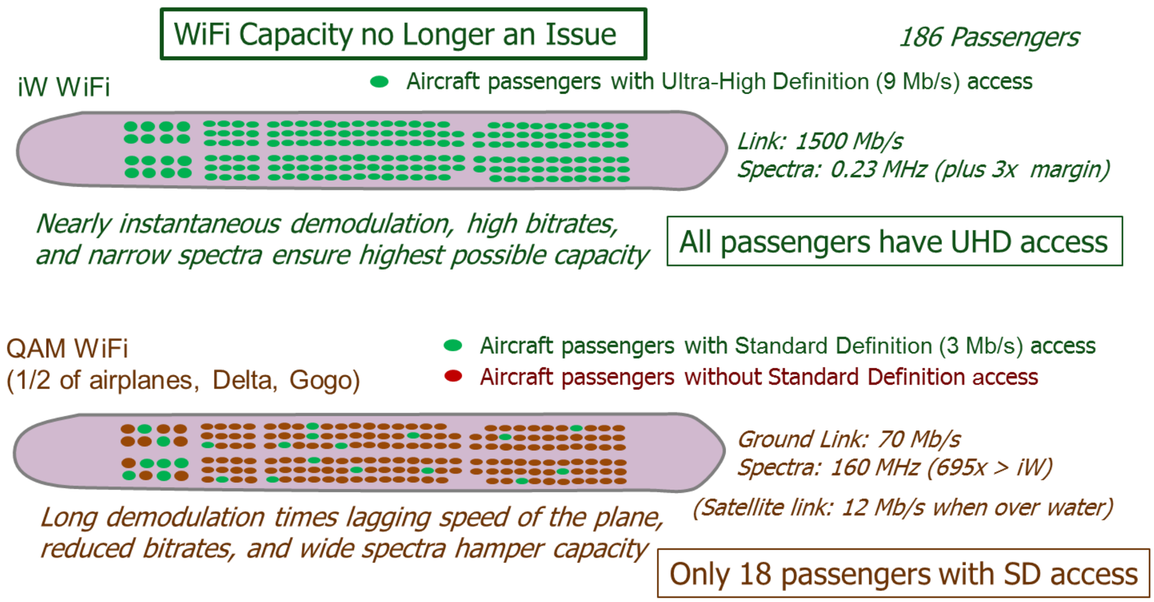

Figure 11. WiFi capacity no longer an issue with IW.

Congested and Contested Spectra, Interference Avoidance

One of the largest impediments to RF communication currently is interference, or desired weak spectral signal being overwhelmed by an adjacent strong signal. While a steeper roll off on filters with tighter accuracy on the front end would help with interference, an indirect solution which offers efficient use of spectra would eliminate interference by moving signals farther apart. In this regard, IW offers an excellent solution to the existing dilemma caused by contention from adjacent signals.

Interference is largely an artifact of a far greater problem, congested and contested spectra caused by the need for increased capacity. Congested spectra is largely due to the large spectral footprint of 256 QAM needed to achieve higher bitrates and is exacerbated by increasing number of channels, hence a lot of big spectral profiles overlapping with each other while contending for congested spectra.

IW eliminates this pronounced interference by substantially reducing spectral congestion, with spectral profile at least 7 times smaller and throughput 15 times faster than 256 QAM. Because the IW signal is essentially a fixed-frequency clock with essentially distorted duty cycle from the modulation, spectra is very tight, forming an impulse function in the frequency domain at smaller modulation deviations. Throughput, unimpeded by back-end channel noise and truncated signal-space leads to a link spectral efficiency (LSE) above 18 times greater than 256 QAM.

This advantage translates into signal separation roughly 18 times farther apart on the spectrum for the same overall capacity, or moving a strong signal 18 times farther away from a target small signal. Interference on a weak signal from an adjacent strong signal is prevented by higher capacity of IW providing efficient use of spectra, eliminating congested and contested spectra.

Invisible Communication, Negligible Latencies

Another disruptive capability of IW is invisible communication. By invisible, a key cyber resilient capability, a link can start up or hop to new frequency within less than 10 nanoseconds and communicate 375 Mb or higher of data and then turn off before any hostile or external entity can detect the presence of a UPM signal. Current communication methods require more than 500 milliseconds to lock to a new frequency, let alone detect any transmitted data, allowing 375 Mb or higher of IW data to be communicated at 1.5 Gb/s without detection. This can be repeated with frequency hopping, transmitting 375 Mb of invisible data after each transition to a new frequency, making all communication effectively invisible. Frequency hopping, traditionally not used because of extremely low effective bit rates owing to long transition (hop) times on the order of seconds, now becomes feasible and effectively invisible with UPM, shown in Figure 12.

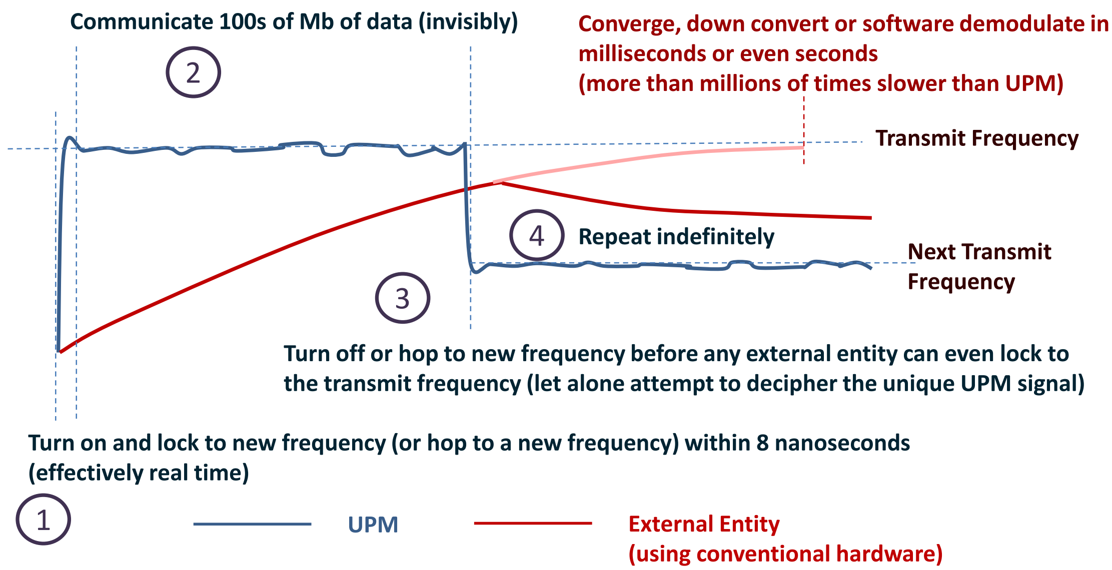

Figure 12. Negligible latencies of UPM lead to invisible communication.

Automated inventorying, Item-Level Tagging

Another application where IW advances brings huge performance gains is wireless item-level tagging (ILT), the ubiquitous replacement of barcodes. Radio Frequency Identification (RFID) and Barcodes/QR codes are the two forms of data collection used to process and track items. Although RFID has been around for more than 50 years, a trip to the store reveals that barcodes dominate in the tagging/tracking of most items. Notwithstanding the automated tagging advantage, existing RFID tags do not surpass the performance of barcodes. This is due to the large size-to-sense-range ratio. As antenna size and power increase enough to achieve adequate sense range, ubiquitous use becomes prohibitive due to cost and increased size. Truncated range, high sense latency, and cost are the major limitations of existing wireless tagging technology.

Current RAID RFID commonly uses amplitude shift keying (ASK) modulation, which has other inherent limitations that inhibit ILT. While QAM is not practicable for ILT given software demodulation and large latencies, throughput would be closer to IW in Figure 13. Receiver sensitivity is still orders of magnitude less for IW than both ASK and QAM. Architectural constraints limit receiver sensitivity for QAM and ASK, whereas only the physical noise floor limits the sensitivity of IW.

In Figure 14, Friis transmission equation and sensitivity levels from Figure 13, IW increases transmission range 23 times farther than ASK while increasing throughput by 300,000 times and decreasing power by 1,000 times. In the case of QAM, improvements are even more pronounced. Die area and read times are substantially lower for IW than ASK and QAM. These advances allow IW to compete with barcodes for ILT by keeping die area substantially smaller to rival barcode costs, keeping read range significantly higher than barcodes while offering automated tracking, and keeping latencies negligible for faster read times.

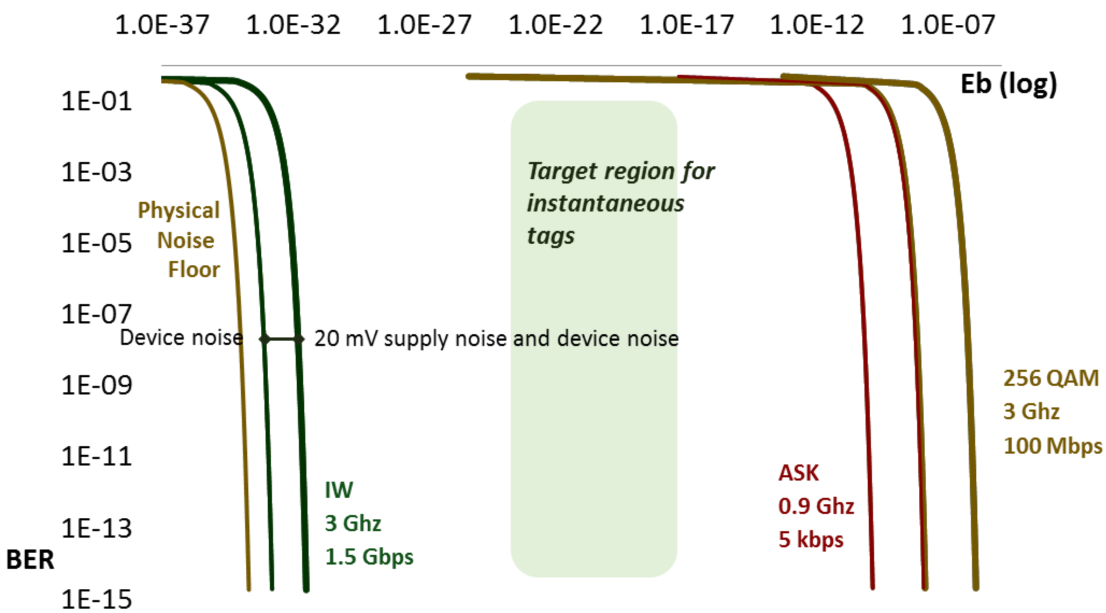

Figure 13. BER, sensitivity, of modulation methods.

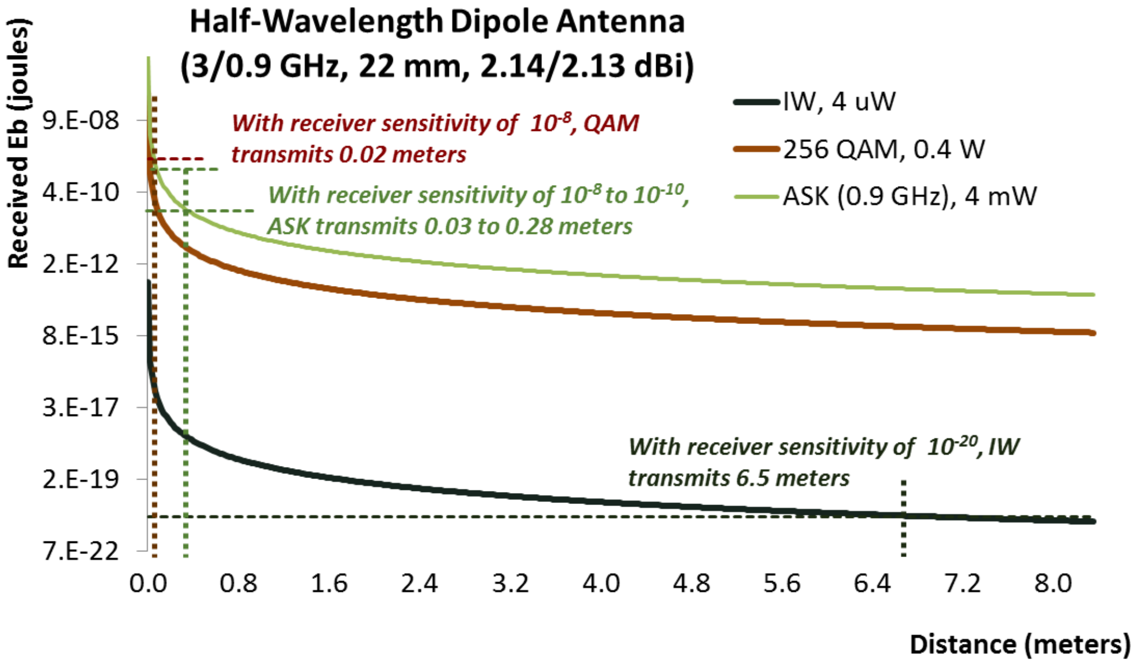

Figure 14. Tag transmission ranges per sensitivity.

Currently best in class wireless tags, RAIN RFID using ASK modulation, tout sensitivity of -27 dBm and a range of 4 centimeters, which matches the pessimistic side of modeling of ASK in Figure 13, showing a sensitivity between -30 dBm and -50 dBm and a transmit range of 3 centimeters to 28 centimeters, depending on induced supply noise. Barcode readers have read ranges about 10 times longer than 4 centimeters. Sense latency for ASK also approaches that of barcodes, in the higher milliseconds, despite automation. Tag costs are about 10 times those associated with barcodes. Thus barcodes remain unchallenged in ubiquitous item tracking. Barcodes, however, require manual orientation besides limited range, adding high substantial costs throughout supply chains via inventory errors and increasing process time, seen in Figure 15.

With barcode sized antenna, Gain ICs' IW tags extend range between 2 to 6 meters, substantially farther than existing methods. Die area for an IW tag, the dominant cost when upfront costs are amortized to negligible over high volume, can be kept below barcode costs at $0.04 per item, the lowest cost for a manual scan of a barcode. With millions times faster communication, in the low nanoseconds, IW tagging can now inventory 10,000s of items in mere seconds, millions of times faster than existing RFID. All these advances make IW uniquely positioned as a wireless tagging solution, with the huge advances required to achieve true ILT, to replace barcodes everywhere.

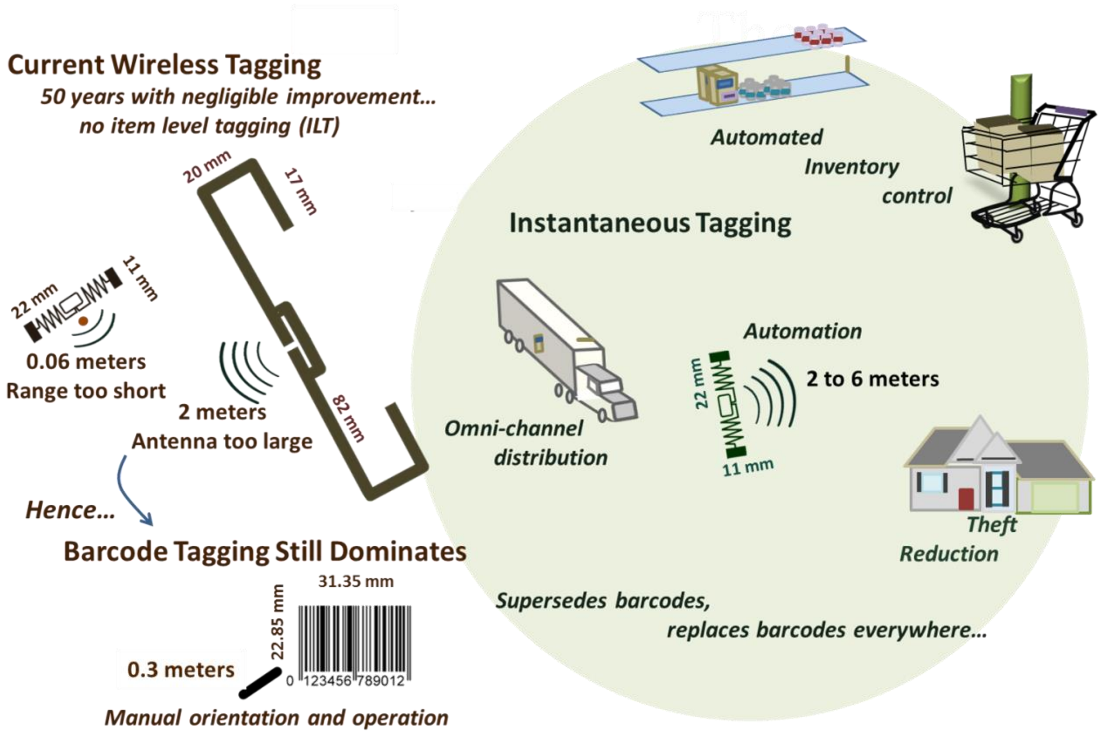

Figure 15. IW ILT surpasses performance of existing methods.

INSTANTANEOUS LOOP

The key to achieving IW is instantaneous loops (IL) to achieve UPM. By eliminating large loop filtering of typical phase locked-loops (PLL), and achieving exact phase tracking with tracking bandwidth to half of the reference frequency, IL achieves phase coherence seen in jitter transfer function and time domain plot of Figure 16.

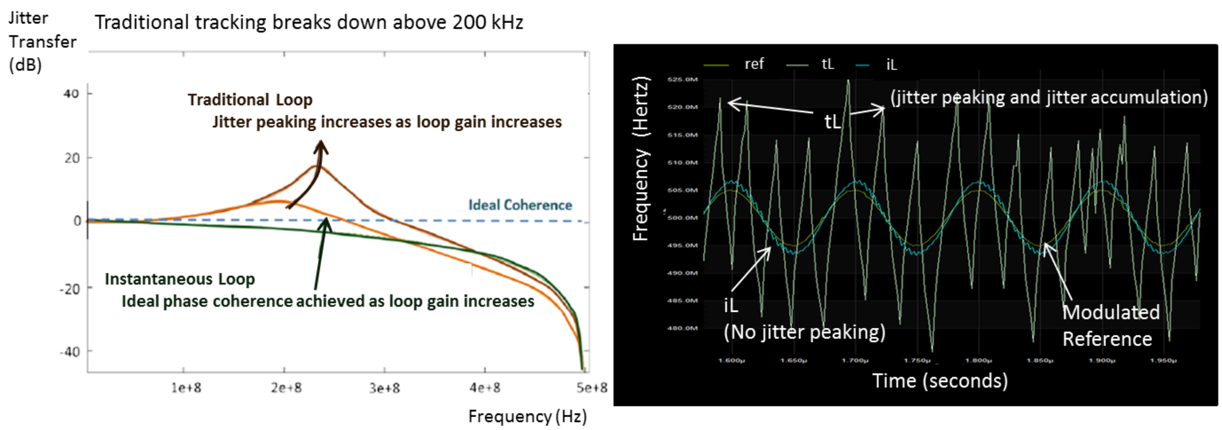

Figure 16. Phase coherence of I,lkL demonstrated as ideal phase tracking.

The high bitrate of IW modulation can be seen in Figure 17, with a modulation amplitude of 10 MHz. The modulation deviation is high to illustrate the stability regardless of swing. In the case of modeling just presented, the modulation amplitude was set to 10 Hz, given the high reliability along with greater range of the low sensitivity. This translates in to link spectral efficiency (LSE) of 75 M(b/s)/Hz, orders of magnitude above any other RF communication link. For instance, 256 QAM typically has LSE around 4 (b/s)/Hz.

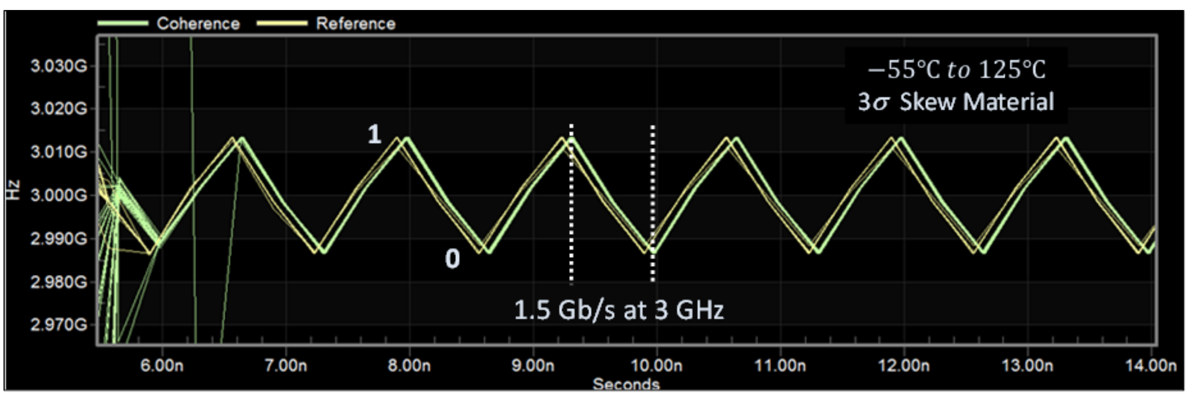

Figure 17. Ideal modulation, with bitrate at half of carrier frequency.

Ideal phase tracking of IL leads to the ideal phase modulation/demodulation of IW. No other existing physical link, with high bitrates, can be simulated as with IW, thus ensuring far greater design validation. Such a simulation is shown as modulated and demodulated signal transmitted and received across and entire IW physical link in Figure 18. IW can achieve bitrates at half of the transmit frequency, 1.5 Gb/s at 3 GHz transmit as shown in Figure 17.

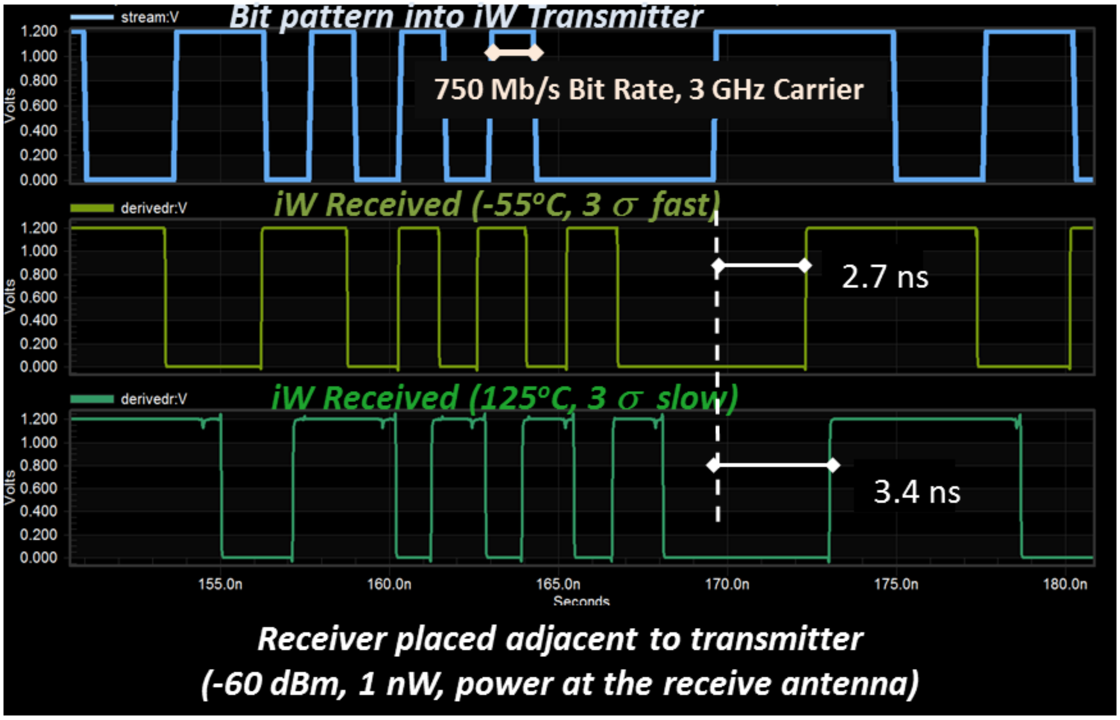

Figure 18. Negligible latencies from transmit to receive, transmitter and receiver adjacent to each other.