

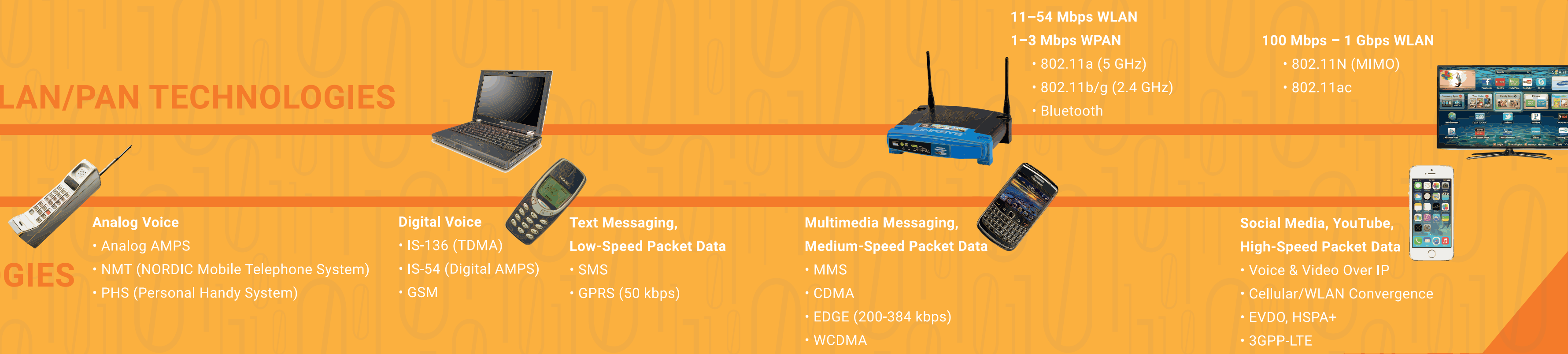
HOW DO WE COMMUNICATE WIRELESSLY?

Wireless communications can enable us to access, process and create content anytime from anywhere, and have transformed the way we live, work and socialize.

MOBILE & WIRELESS NETWORKING EVOLUTION

WIRELESS LAN/PAN TECHNOLOGIES

CELLULAR TECHNOLOGIES



2015 GLOBAL MOBILE DATA

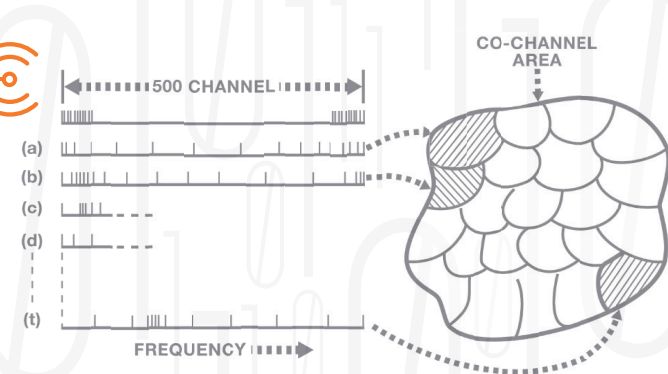
- Mobile data traffic was 3.7 Exabytes per month in 2015, the equivalent of 921 million DVDs each month or 10,155 million text messages each second.
- In 2015, mobile data traffic grew 1.7-fold (74%).

KEY TECHNOLOGY CONTRIBUTIONS

1950-1985

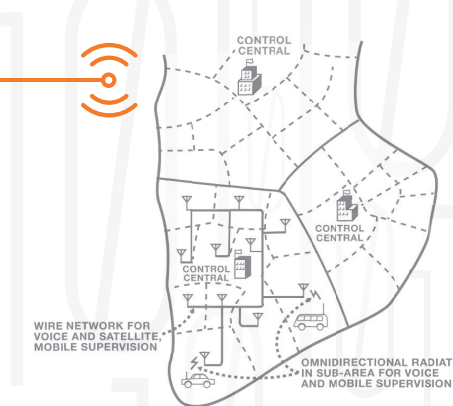
Frequency Reuse

Multi-area Mobile Telephone System
Frequency assignments in a co-channel area. No mutually interfering channels are used in any single sub-area.



Handoffs

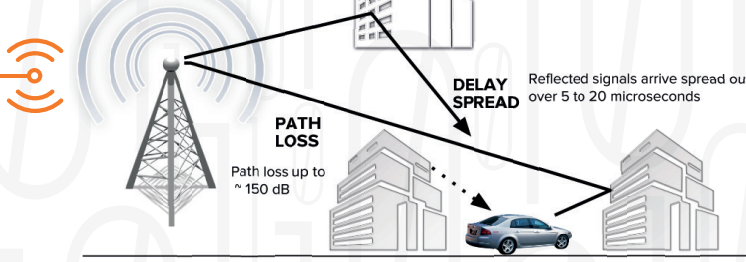
Multi-area Mobile Telephone System
Geographic layout of multi-area system showing control centrals, sub-areas, and interconnection network.



1985-1995

Cellular Voice Calls

Rapid fading of 20 to 30 dB in level at rates of about 100 times per second.



The Viterbi Algorithm

- Applications to Convolutional Decoding, Channel Equalization and Decoding of Modulation Waveforms
- Error bounds for Convolutional Codes
- Maximum Likelihood Sequence Estimation

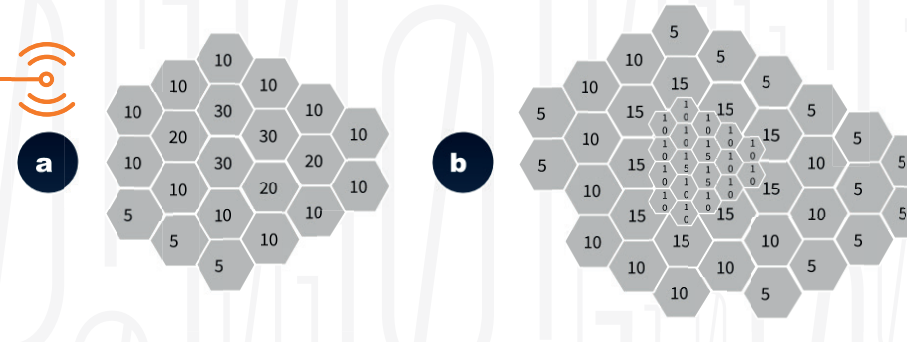
1995-2005

Wireless System Advances

- Feedback**
- Power control essential to modern cellular systems
 - Adaptive coding and modulation matches transmission efficiency to channel SINR
 - Hybrid ARQ enables robust packet error recovery at higher layers
- PHY**
- Adaptive FH and error control coding (GSM systems)
 - Direct Sequence Spread spectrum and error control coding (CDMA and WCDMA)
 - OFDM introduced in 802.11a,g
- Modern Error Control Coding**
- Introduction of turbo codes in 3G.

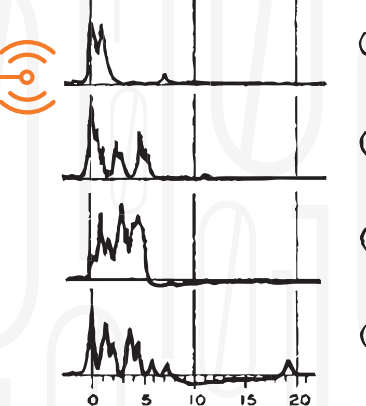
Cell Splitting

A High-Capacity Mobile Radiotelephone System Model Using A Coordinated Small Zone Approach
Growth pattern in a small-zone model.



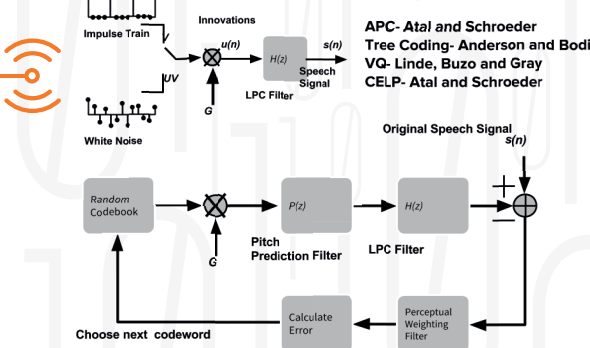
Understanding the Channel

Echoes in Transmission at 450 Megacycles From Land-to-Car Radio Units
Sample pulse patterns received at various locations.



Digital Speech Compression

Predictive Coding of Speech - Codebook
Excited Linear Prediction



Acoustics for Small Form Factor Handsets

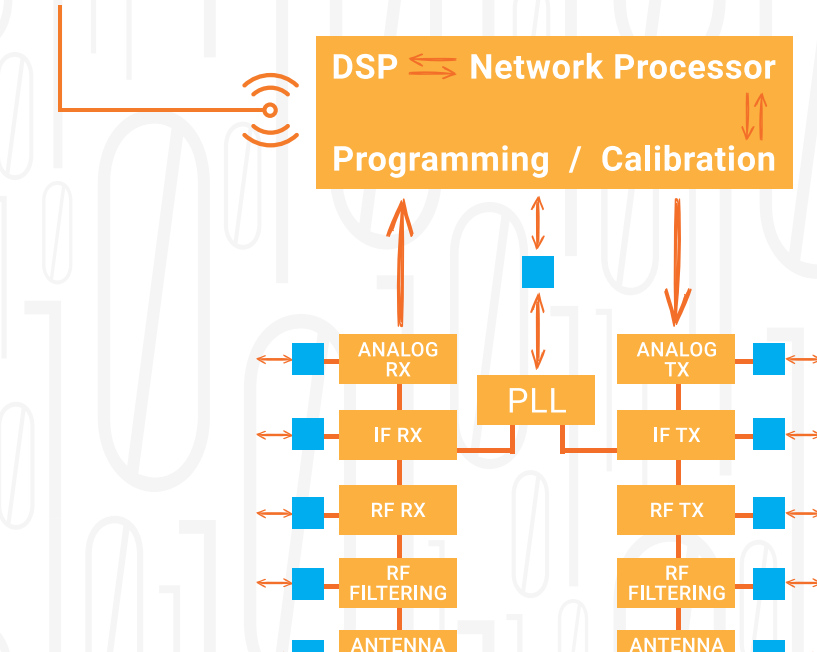
- ACOUSTIC CHALLENGES**
- BACKGROUND NOISE KEEPS YOU FROM HEARING
 - CELLULAR SIGNAL FADES CAUSING SPEECH OUTAGES
 - ANNOYING POPS AND CLICKS
 - UNEXPECTED LOUD NOISES HURT YOUR EARS
 - LISTENER COMPLAINS ABOUT BACKGROUND NOISE
 - ACOUSTIC ECHOES MAKE IT HARD TO FOLLOW CONVERSATION
 - PUFFS & OTHER SOUNDS WHEN SPEAKING IN WINDY ENVIRONMENT
 - SPEAKER AT OTHER END OF LINE IS TOO QUIET
 - WIDEBAND SPEECH
 - SPEECH RECOGNITION

Advances in VLSI

- Application Processors (CPUs, GPU, Video, Image Processors, audio processors) for cellphones
- Adoption of wifi
- Single Chip cellular devices
- Multi-modal wireless (BT+FM+WLAN+GPS+....)



CMOS RF

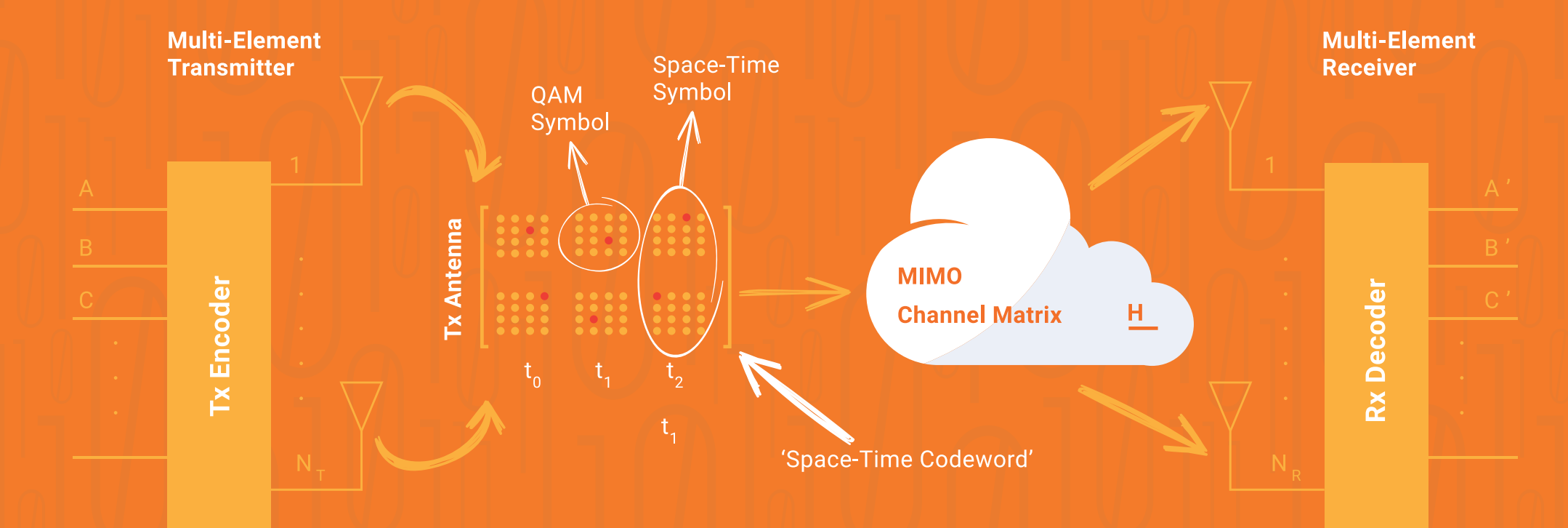


KEY TECHNOLOGY CONTRIBUTIONS 2005-2015

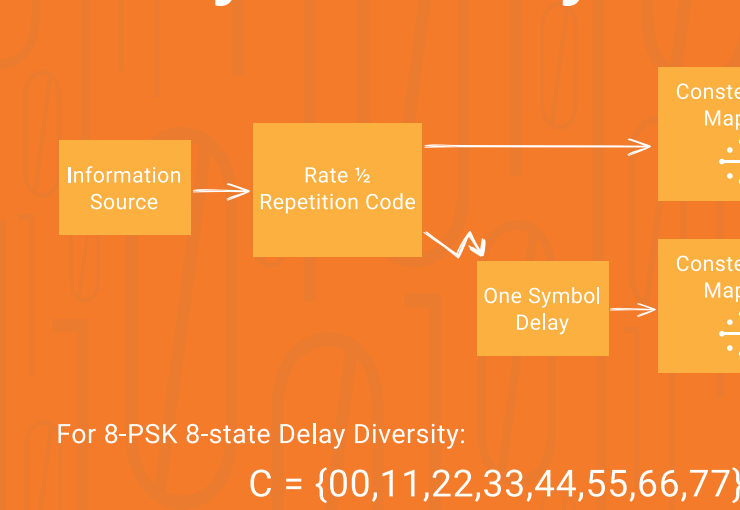
- Mobile data traffic in 2015 was equivalent to 15 times the volume of global mobile traffic five years earlier.
- Mobile data traffic grew 3.5 times faster than global fixed IP traffic in 2015.

MIMO and Space-Time Coding

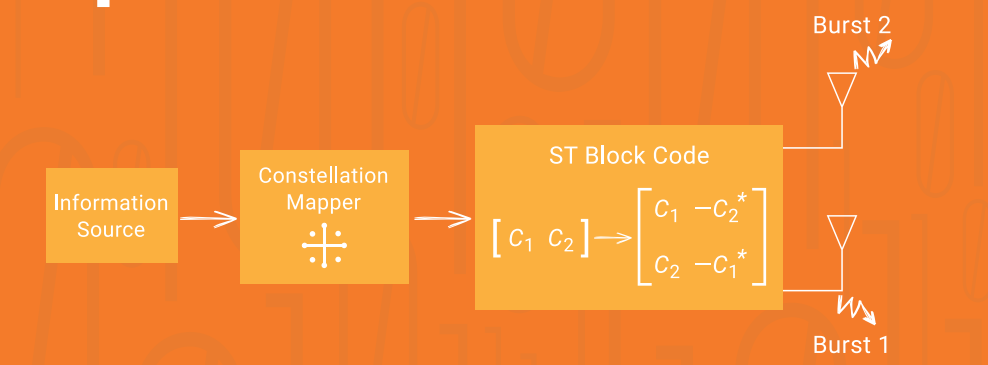
- By use of multiple antennas at both ends of the link, MIMO & STC aims to provide higher throughput, and or diversity advantage to the user.
- Data is distributed across multiple transmit antennas operating on the same carrier frequency. Through appropriate code design the data is spread in spatial, frequency and temporal dimensions.
- Performance benefits can be flexibly traded between improvements to coverage, capacity, and data rate



Delay Diversity



Space-Time Block



KEY TECHNOLOGY DRIVERS, 2015-2025

Better Management of Licensed & Unlicensed Spectrum

- WiFi continues to evolve
- License Assisted Access (LAA)
- LTE/WiFi Aggregation (LWA)

5-10 Gbps mmwave PAN

Evolution of RF Front Ends to Accomodate Larger Bandwidths and Band Proliferation

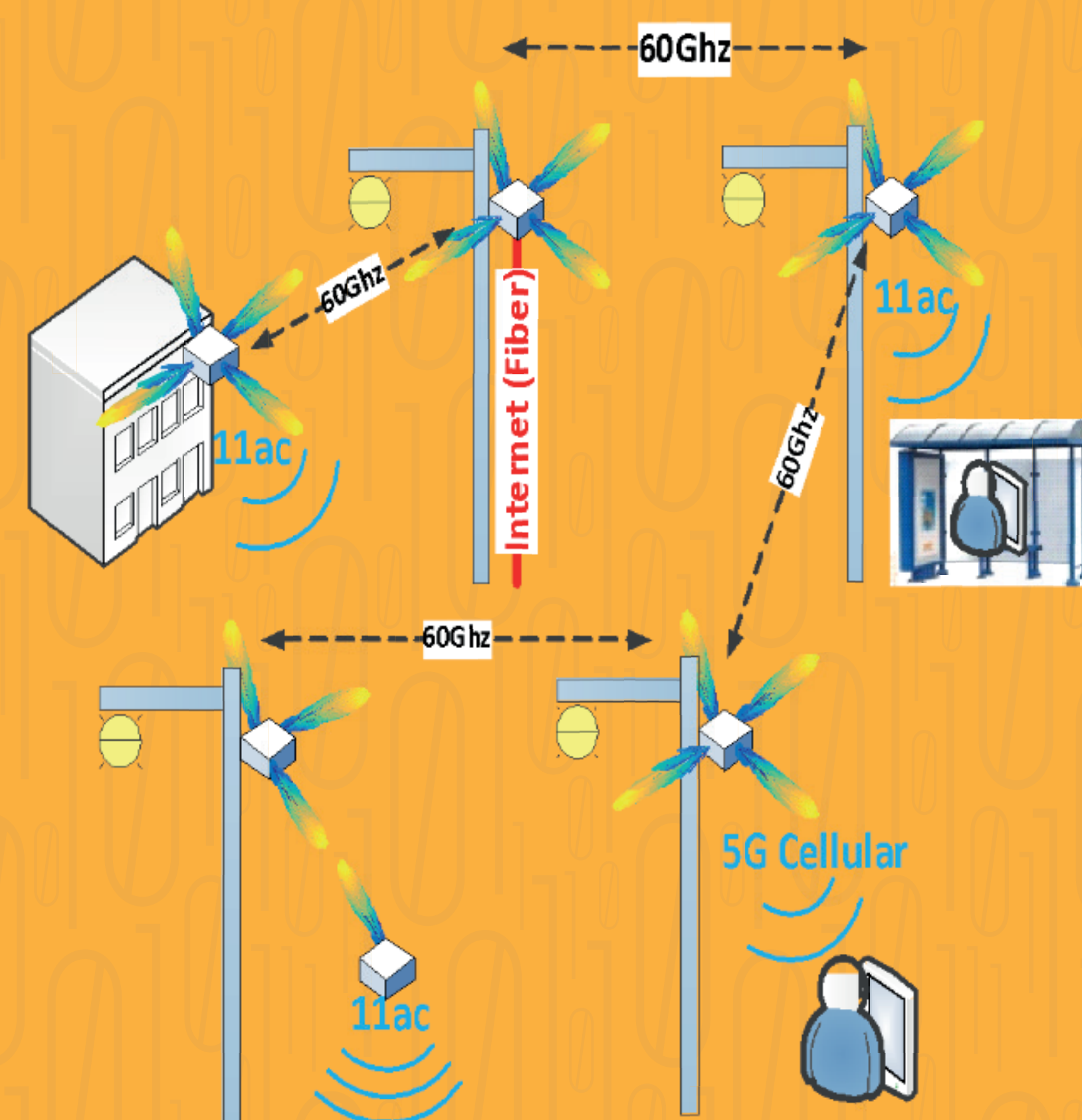
Massive MIMO

Sensors

Battery Technology

New 5G Waveforms

- Faster than Nyquist signaling, OFDM with less PAR
- Higher bandwidth and capacity at lower cost



Spectrum Efficiency Improvement from 2G-4G

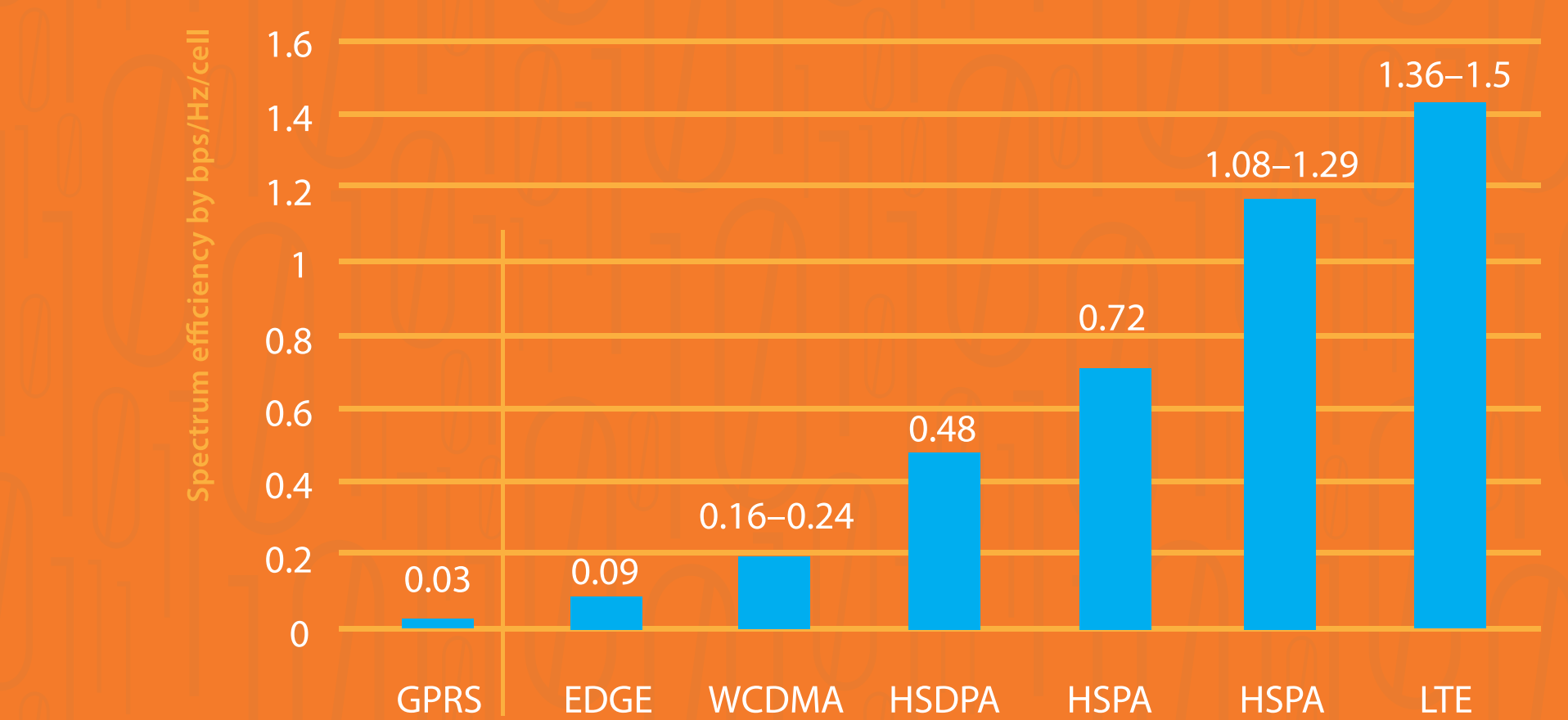
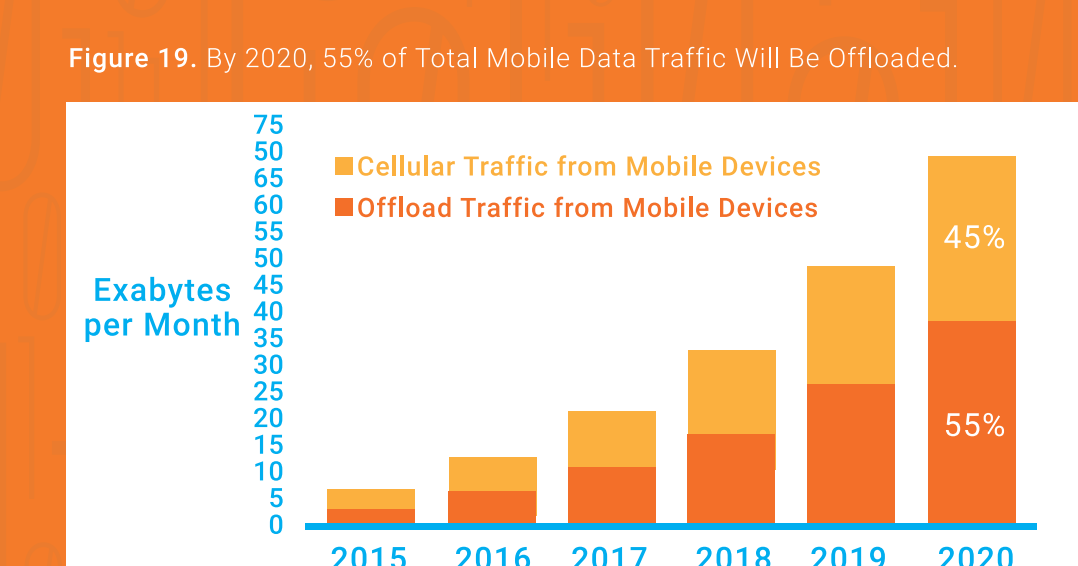
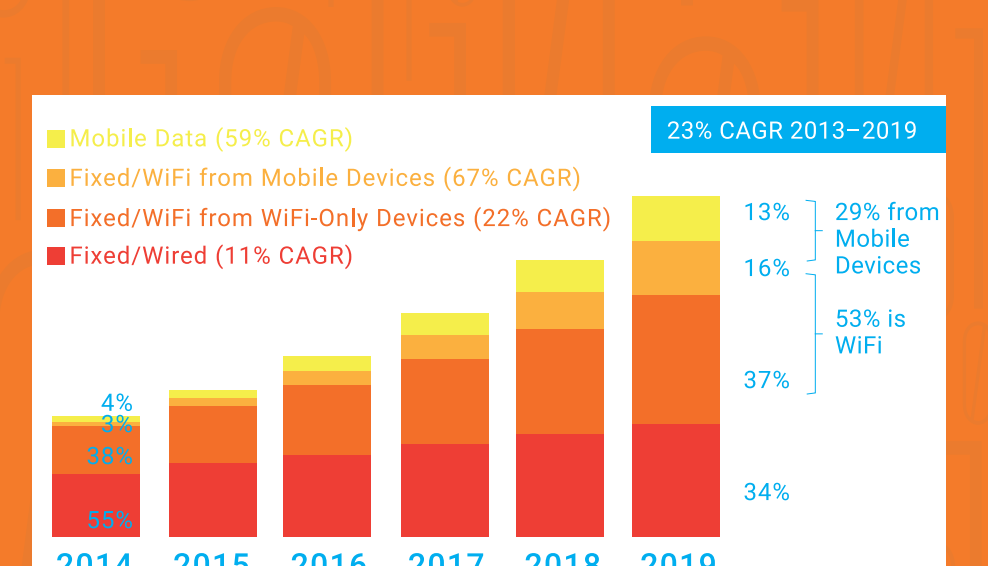


Figure 3-9: Spectrum efficiencies assumed in FCC analysis of spectrum requirements (Source: FCC)

WiFi Traffic in Mobile Devices



WiFi Traffic by Access Technology



Offload pertains to traffic from dual-mode devices (excluding laptops) over WiFi or small-cell networks. Source: Cisco VNI Mobile, 2016.