Wireless Communications 2020

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INTRODUCTION

The news is full of stories of rapidly increasing mobile data usage and the new gadgets that drive this growth. Smarter smartphones, Machine-to-Machine communications and the "Internet of Things", wearable devices, and ubiquitous video sharing all fuel the trend. In this article, the various components of wireless network capacity are defined and the technical tools needed to grow capacity are examined. By reviewing the ways network capacity can be increased, common themes are identified which point to the most likely way forward for wireless communications in the year 2020.

THE PROBLEM

Nearly every forecast of future mobile data usage projects ten to twenty times current (2013) usage volume by 2020. These levels of data intensity will put tremendous strain on wireless communications networks, and have a direct impact on the architecture and implementation of the base station and user-equipment (UE).

Radio engineers measure data system capacity in bits per second per hertz per unit area (bps/Hz/km²). The units imply the various ways to increase system capacity:

1. Increase bps/Hz with more efficient coding schemes
2. Increase bits per second (higher order modulation and/or multiple antenna techniques, e.g., MIMO)
3. Increase Hz (wider bandwidths)
4. Fewer square miles per base station (higher base station density; more sites per square kilometer)

The first item is governed by Shannon's Law from the field of Information Theory. Current coding schemes very closely approach Shannon's theoretical limit. Addressing the last three items drive an interrelated set of responses from both the base station and UE hardware. Substantial pressure is placed upon the transport component of the RAN as well.

RADIO SOLUTIONS

The most direct approach to increase data system capacity is to increase the modulation depth of the digital signaling. Both LTE and 802.11 ("Wi-Fi") use a depth of 6 bits per symbol. Cable systems can achieve a depth of 8 bits

per symbol. Higher modulation depth is costly, however, because it requires amplifiers with higher linearity (each additional 2 bits per symbol requires a halving of the maximum amplifier EVM) and higher SINR ratios to successfully demodulate. Higher linearity generally results in very low transmitter efficiencies, which are particularly costly in battery-powered UEs; and mobile systems suffer from significant interference, limiting the achievable SINR. For example, if mobile system modulation depth were increased to 8 bits/symbol, the 33% increase in capacity would typically be usable by less than 10% of the mobile users due to interference from adjacent nodes.

Increased modulation depth could have a larger impact on capacity if the interference from adjacent nodes could be managed effectively. Various architectural solutions have been proposed to manage interference and are discussed later.

Multiple antenna technologies ("MIMO") have been developed in order to achieve increases in capacity without commensurate required increases in SINR. Theoretically, channel capacity can be multiplied by min(M,N) in a system using M transmitters and N receivers at any arbitrary SINR. Achieving this multiplied capacity requires orthogonal propagation paths between the (M,N) antenna sets. The LTE standard supports up to 4x4 (M=N=4) MIMO, which theoretically can deliver an equivalent of 24 bits/symbol.

Achieving the promise of multiplied capacity via MIMO is primarily limited by the large number of antennas required and by the obtainable channel orthogonality. A simple UE for North America may include two frequency bands and Wi-Fi capability for a total requirement of 12 individual antennas to support 4x4 MIMO. Compromises in the implementation of the antenna systems (e.g., broadband or multi-band antennas) reduce the effective channel orthogonality and therefore the achievable capacity. The practical channel orthogonality in typical urban environments is substantially less than ideal, and measurements show that as min(M,N) increases, the area of sufficient channel orthogonality decreases. Field tests indicate that suitable 2x2 conditions exist over about 50% of a given urbanized area, while 4-path orthogonality exists over only about 10% of the same area. Finally, the multiple

simultaneous transmitters and receivers required places further strain on UE battery life.

SPECTRUM SOLUTIONS

Recently interest has focused on increasing the signaling bandwidth of mobile networks. LTE initially specified channel bandwidths up to 20 MHz, and Wi-Fi up to 40 MHz. LTE-A systems are standardized up to 100 MHz. The immediate impact of wider channel bandwidths is to drive the carrier frequency higher. This is because national spectrum regulators can more easily allocate multiple wide bandwidth channels at higher frequencies, and because radio systems are generally easier to implement when fractional bandwidths (the ratio of channel bandwidth to carrier frequency) are smaller.

There are additional technical impacts to wide channel bandwidths. Amplifiers with larger fractional instantaneous bandwidths tend to be less efficient, impacting battery life in the UE. Wider amplifiers also have more adjacent-channel emissions, which can force the implementation of additional transmitter filtering to meet regulatory mandates. Wider channel bandwidths tend to drive total transmitter power up proportionally as well, in order to maintain a fixed level of transmit power spectral density.

One subtle impact of wider bandwidth that impacts FDD systems is the potential for internally-generated intermodulation products. Intermodulation can be a serious problem in cases where the duplex spacing (spectral gap between transmit and receive sub-bands) is less than a few times the channel bandwidth. Avoiding intermodulation in FDD systems can become quite challenging when combining multiple wideband channels (via the LTE-A feature "Carrier Aggregation"). Intermodulation products can be generated by any component within the RF chain (duplexer, antenna selection switches, coaxial distribution, and antennas).

DENSITY SOLUTIONS

The typical wireless node has three cells (North American usage: "sectors"). The most straightforward way to increase network density is to add cells to existing nodes. This approach is limited due to the physical size of the antennas at their associated frequencies. With the currently prevalent mobile allocations between 450-2500 MHz, the maximum practical cell density is 6 cells/node.

The latest trend in the wireless industry is deploying "Small Cells". The idea is to overlay the existing macro-cell network with limited coverage (typically 30-100m) Small Cells in precise locations where mobile data demand is high. The resulting "heterogeneous network" will have wide area coverage from the traditional macro-cells, and high capacity in the Small Cell hotspots.

Small Cells are essentially miniature base stations. The primary driving factor is their physical form factor. In order to locate them precisely, they need to be small, lightweight, and unobtrusive. Typical deployment cases are on light poles and traffic signals. Electronically, they have the same functionality and backhaul needs of a macro-cell but at about 1-10% of the transmitter power.

ARCHITECTURAL SOLUTIONS

The roadmap of LTE-A includes several network management features designed to maximize the benefit of a heterogeneous network. Many of the LTE-A features focus on managing RF interference within the heterogeneous network, particularly that from the larger macro-cells to the Small Cells. These features are much more effective when the baseband units from a local population of nodes (macro and small) are physically collocated. This network architecture is called "C-RAN" or Centralized RAN.

The C-RAN architecture relocates the Small Cell baseband electronics to the centralized location. The Small Cell location now only has RF components and a "fronthaul" interface. The backhaul of all associated nodes, once collected at the centralized location, can then be aggregated at a cost savings to the operator.

TRANSPORT SOLUTIONS

High wireless capacity requires high transport capacity from the network nodes to the RAN core network. The most popular method of transport is via a fiber optic network, with coaxial and wireless interconnection also in use.

Backhaul refers to the transport from the node baseband to the RAN core network. Typical capacity requirements are 50-300 Mbps per baseband. This can be met using Metro Ethernet over fiber or coax, or with fixed microwave links in the lower microwave bands (up to 18 GHz).

Fronthaul refers to the transport from the radio unit to the baseband electronics. With the advent of C-RAN heterogeneous networks, fronthaul becomes a major implementation issue. Fronthaul transports the raw I-Q samples of the RF signals over the full channel bandwidth, and so the signaling rates are much higher than backhaul—typically 2.5-10 Gbps. This can be met using "dark" fiber optic lines, or with fixed microwave links in the higher microwave bands (above 60 GHz).

THE NEXT GENERATION—"5G"

So-called "5G" wireless has been the subject of open discussions recently in Korea. The typical concept is of a homogeneous network of Small Cells, operating at near-millimeter wavelengths (27-30 GHz), using phased-array antennas with up to 32 azimuthal beams. Each node would have multiple channels arranged in a beam-division multiplex fashion. Very high throughputs are achieved

primarily from the channel bandwidths used (up to 500 MHz), and high network capacity is achieved from a very dense network (each node covers only ~100 m) and higher cell density per node (up to 32).

CONCLUSIONS

Several themes become apparent when discussing how mobile operators can increase their network capacity. The major trend is in increasing carrier frequency and channel bandwidth at the node, UE, and within the transport network. Transmitters must continue to increase their efficiency, particularly in the UE, to maintain reasonable battery life; and all transmit chain components need to continue to improve their linearity in order to support higher modulation schemes and avoid intermodulation problems.

Naturally, talk of "5G" generates significant interest, but the current 5G proposals and demonstrations all illustrate the same themes and trends in the drive to increase wireless network data capacity.

REFERENCES
[1] Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2013-2018

ACRONYMS
RF: Radio Frequency
RAN: Radio Access Network
LTE: Long-Term Evolution
LTE-A: LTE-Advanced
MIMO: Multiple-Input, Multiple-Output (antenna system)
UE: User equipment (e.g., smartphone)
EVM: Error Vector Magnitude
SINR: Signal to Interference-plus-Noise ratio
FDD: Frequency Domain Duplex (separate sub-bands for simultaneous transmit and receive)

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