SCTE
a subsidiary of CableLabs®

Creating Infinite
Possibilities.

How Broadband Customers Can Benefit From Newfangled Wi-fi Multiple User Features

David John Urban

Distinguished Engineer
Comcast

SCTE CABLE-TEC EXPO®22
SEPTEMBER 19-22 • PHILADELPHIA, PA

2022 Fall Technical Forum
SCTE® • CABLELABS® • NCTA

Multiple User Techniques in Wi-Fi

Wi-Fi is a polite protocol with users taking turns in the time dimension to access the radio interface, first checking that the channel is not busy, even requesting to send and waiting for clear to send.

Multiple user techniques allow several users share the frequency and spatial domains at the same time.

The multiuser techniques are called DL and UL MU-MIMO, OFDMA, and spatial reuse.

DL downlink from access point to station

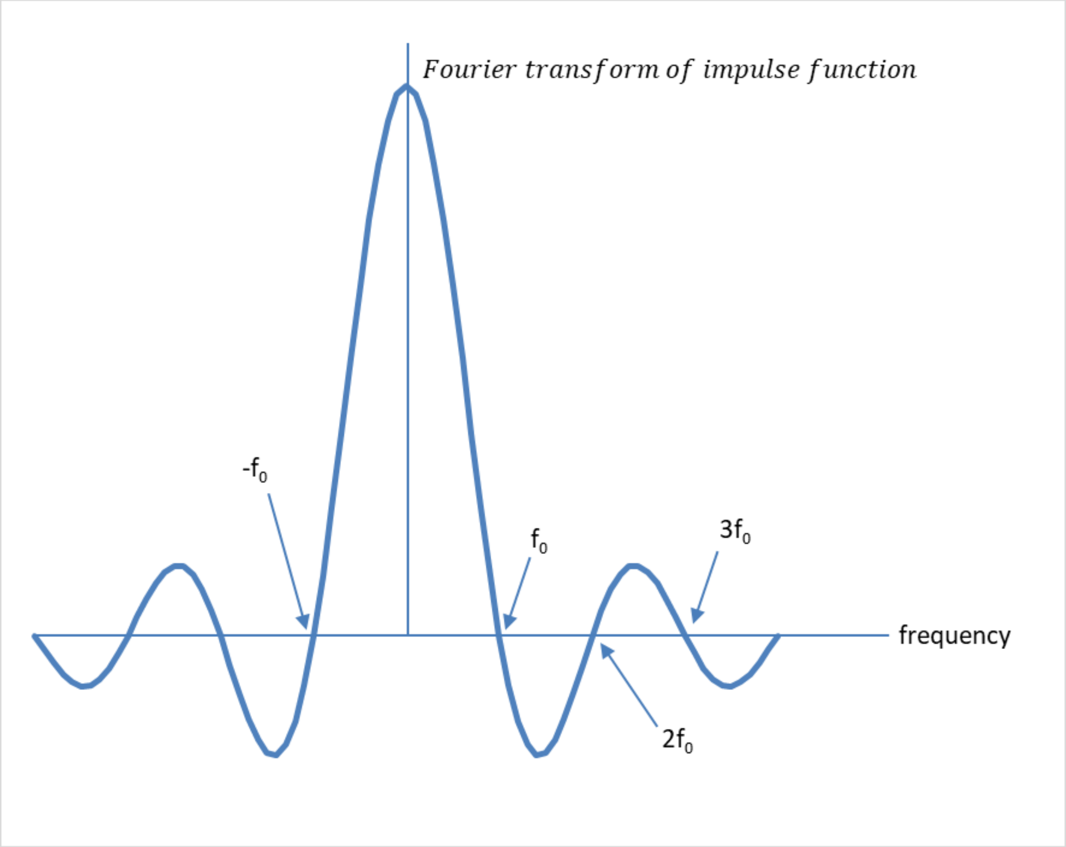
UL uplink from station to access point

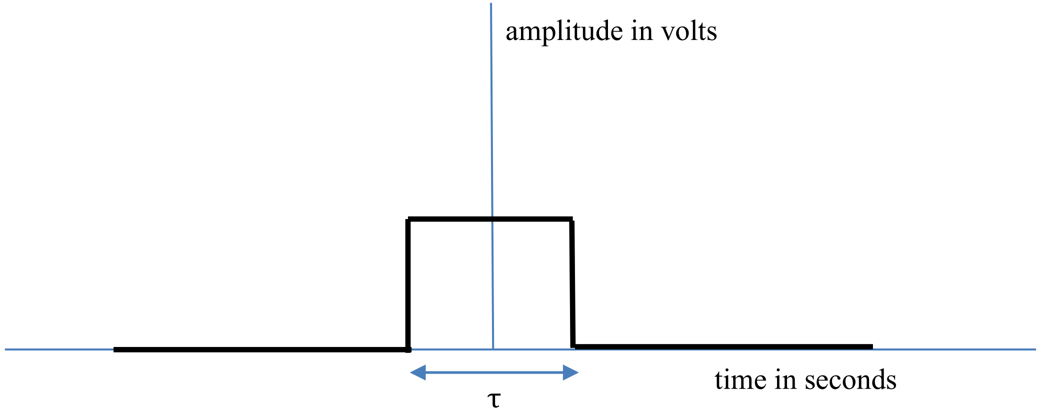
MU multiuser

MIMO multiple input multiple output

OFDMA orthogonal frequency division multiple access

OFDMA combines orthogonal signals from many stations





$$F(\omega) = 2\int_0^{\frac{\tau}{2}} cos(\omega t)dt = 2\,\frac{sin(\omega t)}{\omega}\Big|_0^{\frac{\tau}{2}} = \frac{\sin\left(\frac{\omega\tau}{2}\right)}{\frac{\omega}{2}}$$

$$\omega = 2\pi f \qquad \tau = \frac{1}{f_0}$$

$$F(\omega) = \frac{sin\left(\frac{\pi f}{f_0}\right)}{\pi f}$$

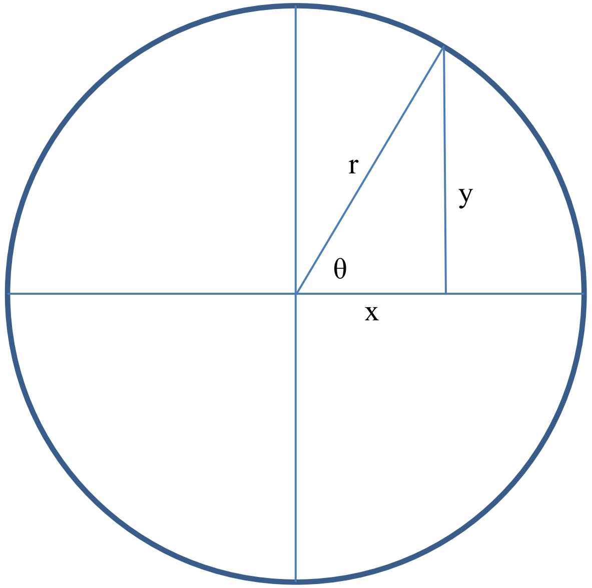
Each orthogonal tone is quadrature modulated QAM

$\cos(0°) = 1$

$\sin(0°) = 0$

$\cos(90°) = 0$

$\sin(90°) = 1$



$$\sin(\theta) = \frac{y}{r}$$

$$\cos(\theta) = \frac{x}{r}$$

SCTE CABLE-TEC EXPO 22
SEPTEMBER 19-22 • PHILADELPHIA, PA

Downlink Multiple User MIMO

Download channel capacity can be increased with DL MU -MIMO

DL MU-MIMO allows a 4x4 AP to send up to four spatial streams to two or more 2x2 STAs.

Measurements show that three spatial streams at high MCS rate are common with two or more 2x2 STAs on the same floor in adjacent rooms and sometimes even further.

DL MU-MIMO with 1200 Mbps PHY STAs enable multiple stations to download in total at over 1.2 Gbps TCP throughput, something a single STA cannot do.

DL MU-MIMO works with multiple stations in high SNR conditions and heavy download traffic demand.

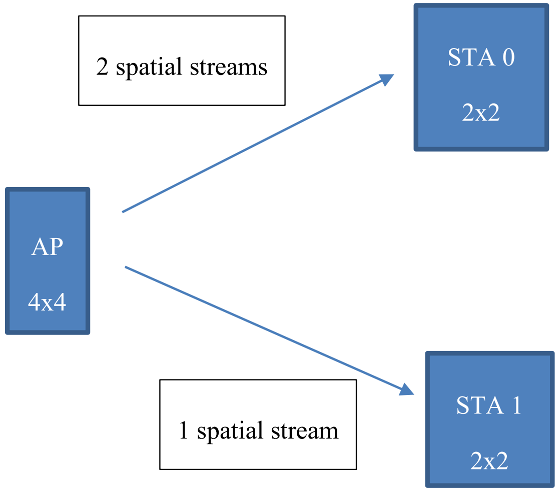
DL MU-MIMO traffic is not observed with low traffic demand or poor SNR conditions.

Some stations are 160 MHz and some stations are 80 MHz

80 MHz 2x2 1200 MHz wireless adapter

DL MU-MIMO Measurement 1200 Mbps PHY Stations

STA	PHY Mbps	Data Mbps	bw MHz	mcs	Nss	mu-mimo
0	617.6	450.9	80	11	1	96.9%
1	1136.7	834.1	80	10.5	2	100.0%
sum		1285.0				



160 MHz, 2x2, 2400 Mbps, 5/6 GHz band wireless adapters

DL MU-MIMO Measurement Two 2400 Mbps PHY Stations

STA	PHY Mbps	Data Mbps	Channel width MHz	MCS	Spatial streams	MU-MIMO
0	1310.0	755.8	160	11	1	90.9%
1	2401.0	1400.8	160	11	2	99.0%
sum		2156.6				

SCTE CABLE-TEC EXPO 22
SEPTEMBER 19-22 • PHILADELPHIA, PA

Uplink multiuser multiple input multiple output allows several stations to transmit spatial streams at the same time.

UL MU-MIMO has the advantage of significant spatial diversity and angle of arrival of spatial streams as the stations transmitting the streams can be in different locations relative to the access point.

Each of the AP antennas receive a combination of all the signals from the stations.

Each antenna of the stations to each antenna of the AP has an impulse response defined by the attenuation and delay of the direct path and various reflections from scattering objects.

UL MU-MIMO the AP estimates the channel matrix, inverts the channel matrix, and multiplies the inverted channel matrix by the received vector to determine the input signals from each of the stations. Thus, all the information streams from the stations can be decoded.

DL OFDMA

Downlink orthogonal frequency division multiple access divides the spectrum into tones and assigns resource units consisting of continuous tones to multiple stations.

DL OFDMA is complementary in the sense that it helps when stations are in a low SNR zone with small amounts of data to transmit.

DL OFDMA is observed when devices are far enough away to forfeit DL MU-MIMO capacity increase and when traffic demand is low.

DL OFDMA is much better at sharing the channel with each device downloading at close to the same throughput.

UL OFDMA

UL OFDMA Measurement Two 2400 Mbps PHY Stations 6 GHz band

Lowest RSSI UL OFDMA

STA	rssi	PHY	Data	Channel width	MCS	Spatial streams	ofdma	tones
	dBm	Mbps	Mbps	MHz				
0	-85	72.5	32.9	160	0	2	100%	1002.7
1	-85	73.5	16.0	159	0	2	100%	1014.3
sum			48.9					

UL OFDMA Measurement Two 1200 Mbps PHY Stations 5 GHz band

Lowest RSSI UL OFDMA

STA	rssi	PHY	Data	Channel width	MCS	Spatial streams	ofdma	tones
	dBm	Mbps	Mbps	MHz				
0	-86	35.2	12.7	80	0	2	100%	491
1	-86	47.4	13.7	79	0.3	2	100%	497
sum			26.4					

Receiver noise floor and channel width for 3 dB noise figure at room temperature

SCTE CABLE-TEC EXPO 22
SEPTEMBER 19-22 • PHILADELPHIA, PA

$$E = k_b T$$

$$k_b = 1.380649 \times 10^{-23}$$

$$N_0 = 10log_{10}(1000 \cdot 1.380649E - 23 \cdot 300)$$

$$N_0 = -174 \frac{dBm}{Hz}$$

$$N = N_0 + F + 10 \cdot \log_{10}(\mathrm{B})$$

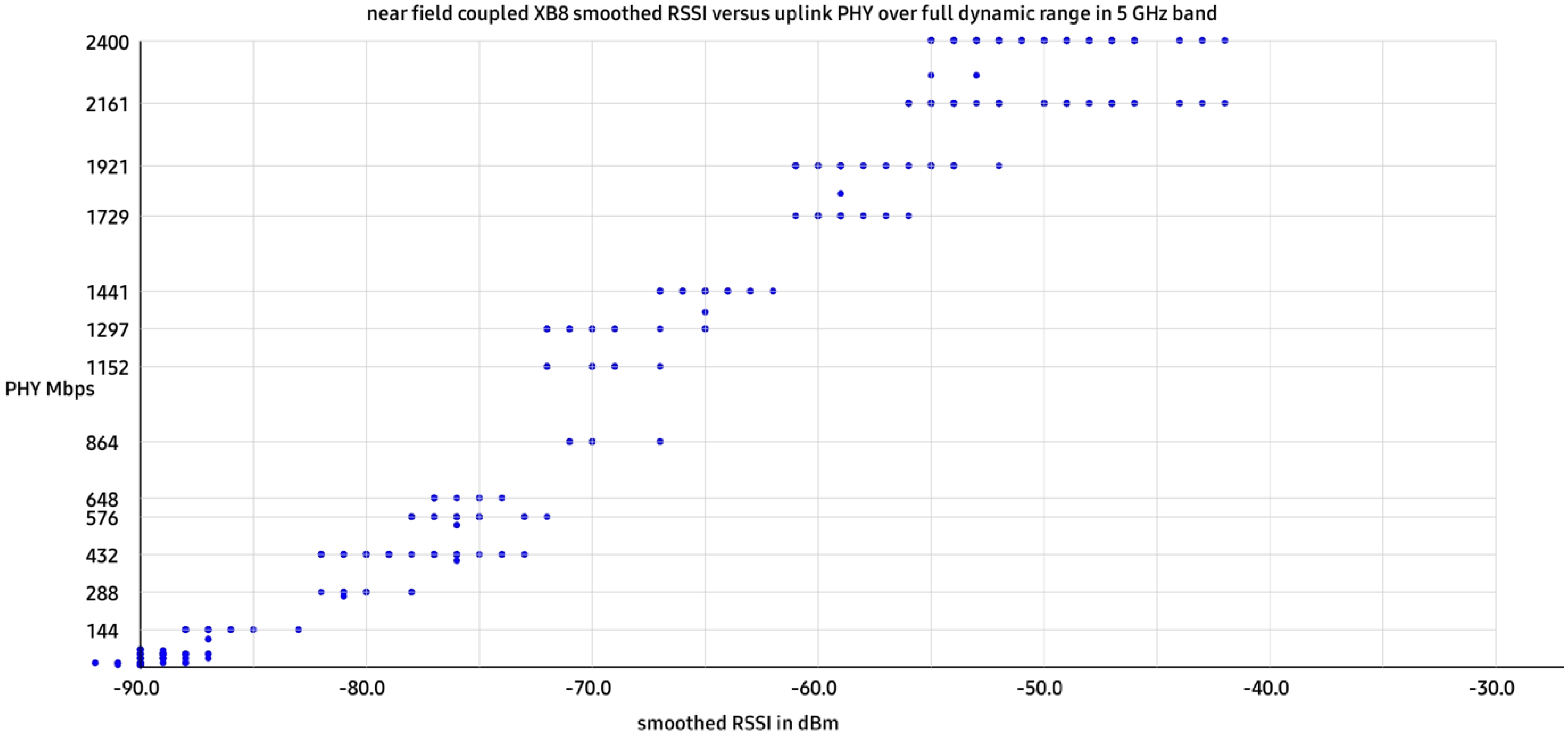
$$B = 20\ MHz$$

$$N = -174 + 3 + 10 \cdot \log_{10}(20E6)$$

$$N = -98\ dBm$$

B	N
MHz	dBm
20	-98
40	-95
80	-92
160	-89

Dynamic Range in the uplink



Distance, receive level for 160 MHz channel width uplink low power indoor station EIRP -1 dBm per MHz

MCS	Rx	PHY	TCP	d 6 GHz
	dBm	Mbps	Mbps	m
0	-86	144	115	132
1	-83	288	230	108
2	-81	432	345	95
3	-78	576	461	78
4	-74	864	691	60
5	-70	1152	922	46
6	-69	1297	1037	43
7	-68	1441	1152	40
8	-63	1729	1383	29
9	-61	1922	1538	25
10	-58	2161	1729	21
11	-56	2401	1920	18

frequency	wavelength
MHz	mm
2412	124.3
5500	54.5
6345	47.2

$$L = A_0 + 35 \cdot log_{10}\left(\frac{d}{d_0}\right) + L_{floors} + L_{walls} + N_\sigma$$

EIRP per MHz	-1.00	dBm/MHz
channel width	160.00	MHz
channel width	22.04	dBMHz
EIRP	21.04	dBm
Antenna Gain	2.15	dBi
Beamforming Gain	0.00	dB
total transmit level	18.89	dBm
chains	2.00	
transmit level per chain	15.88	dBm per chain

$$R = EIRP - L + G$$

$$A_0 = 20 \cdot log_{10}\left(\frac{4\pi d_0}{\lambda}\right)$$

SCTE CABLE-TEC EXPO 22
SEPTEMBER 19-22 • PHILADELPHIA, PA

PD and SRP

PD is power detect which allows transmission at lower level for neighbor signals above -82 dBm.

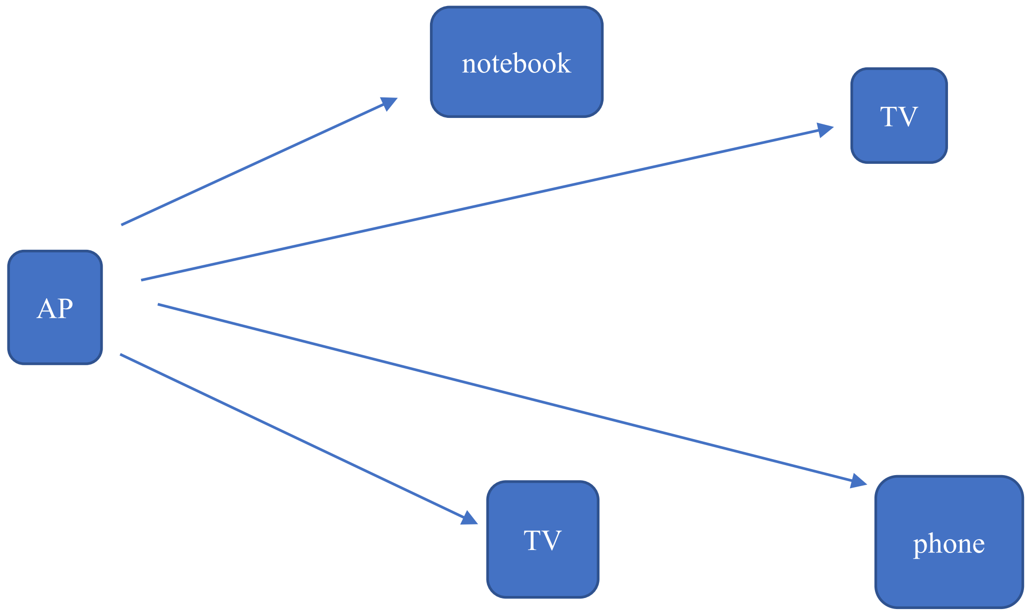
With PD a neighbor RSSI of -72 dBm allows transmission at a 10 dB reduced level.

SRP is spatial reuse parameter, much more powerful but requires neighbor to also have SRP.

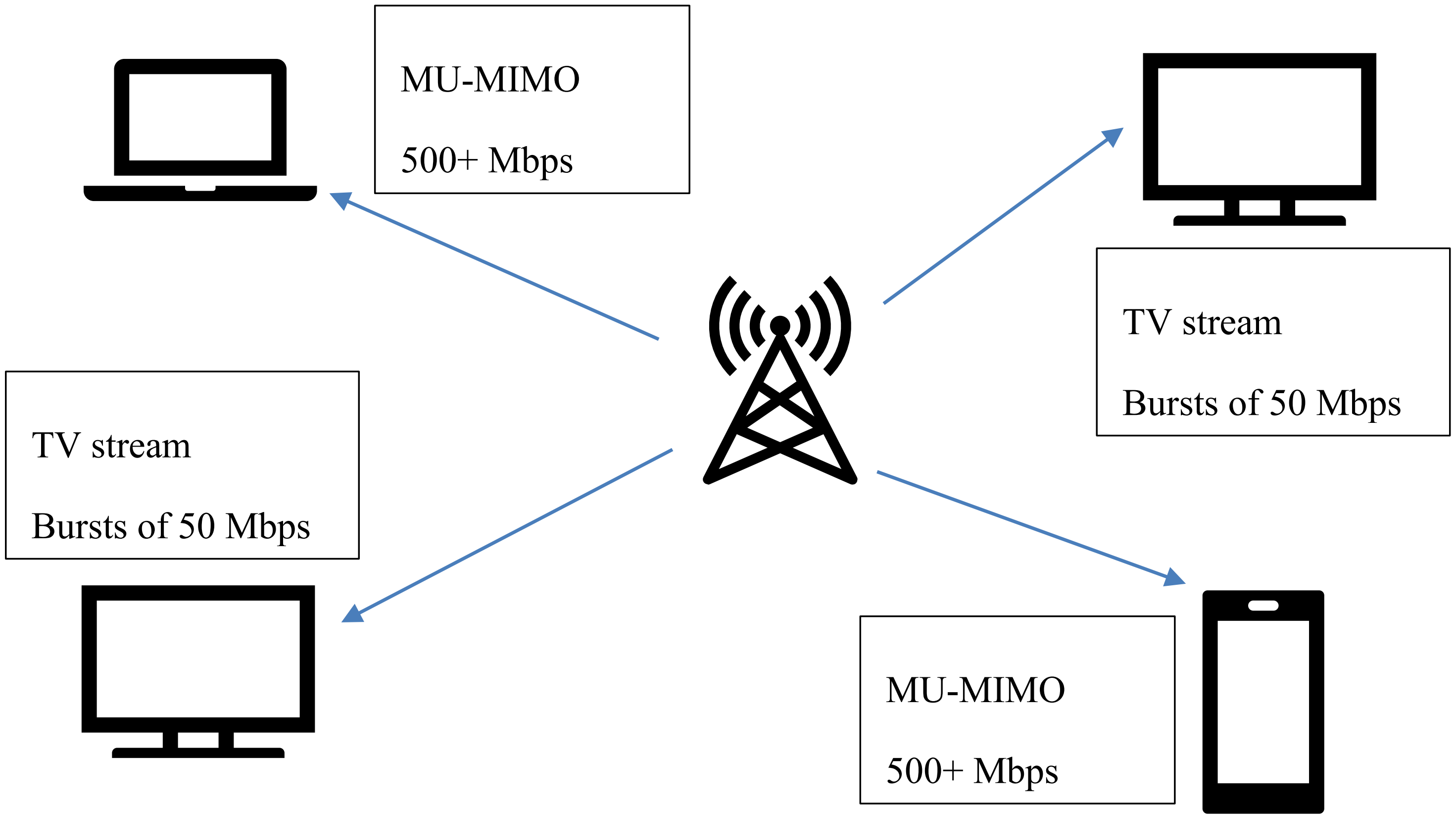
A neighbor trigger of an UL OFDMA signal will tell the AP the path loss to the neighbor and the tolerable level of interference.

The SRP AP can calculate a transmit level that will make sure the neighbor will receive an acceptable level of interference for the upcoming UL OFDMA.

Mix of traffic with MU phone, computer, and two TVs



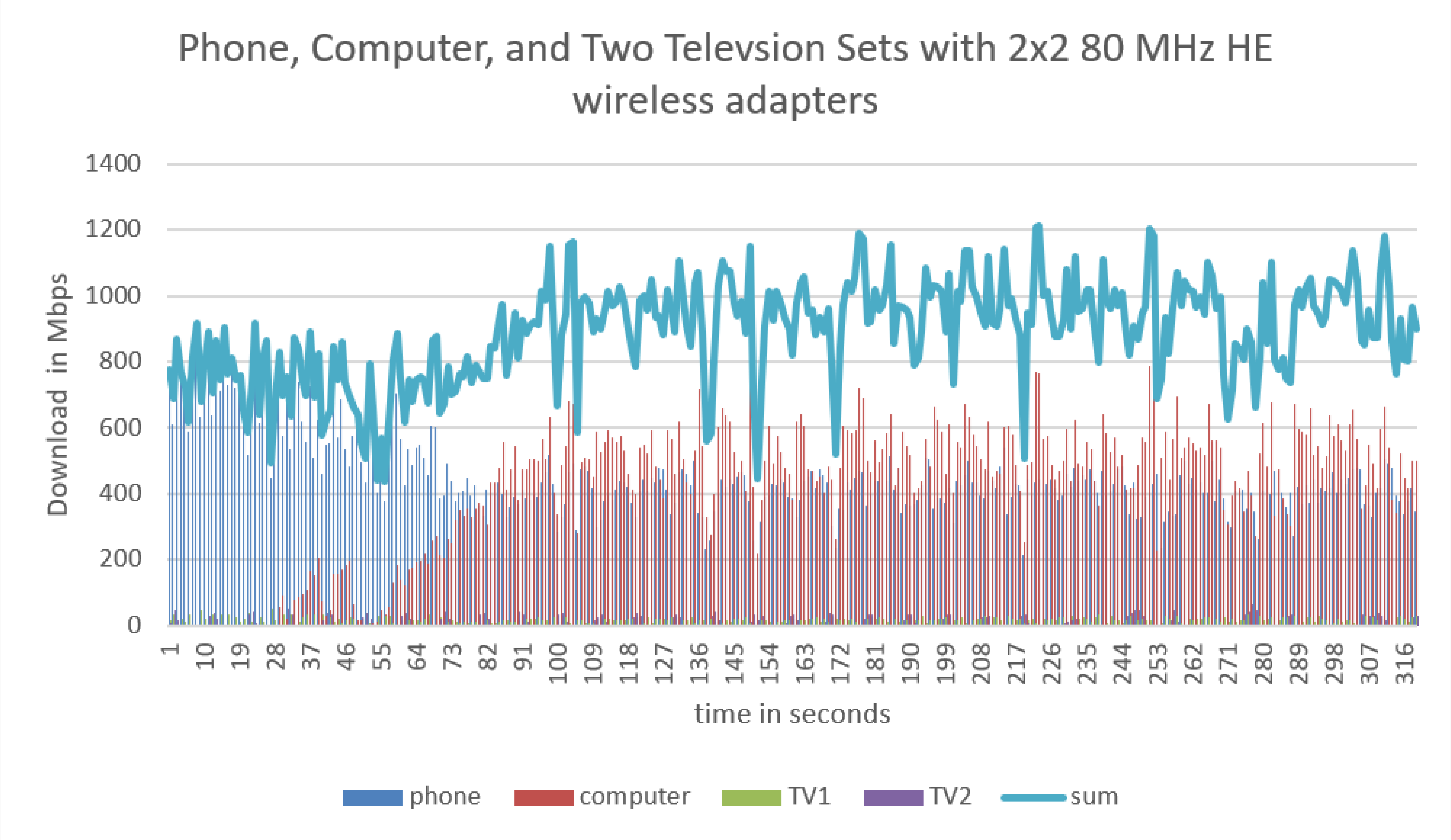
DL MU-MIMO and UL OFDMA traffic mix



Statistics of Throughput with Four MU devices

Stat	phone	computer	TV1	TV2	Sum
average	455.9132	407.8673981	15.32821	8.530408	887.6392
std	126.2928	208.0782331	9.354155	14.13454	152.5777
max	917.4	785.2	49.7	64.5	1212

DL MU-MIMO and UL OFDMA Measured traffic mix



SCTE
a subsidiary of CableLabs®

Creating Infinite Possibilities.

Thank You!

David John Urban

Distinguished Engineer
Comcast