Mobile Systems

Lecture 6 – Mobile networks

4 / 03 / 15

COMP28512

Steve Furber & Barry Cheetham

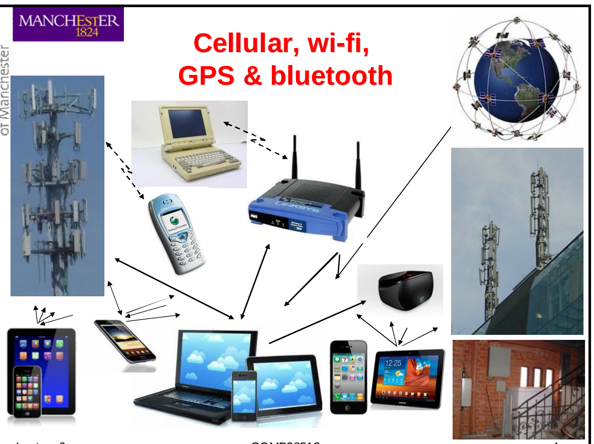
Evolution of mobile networks

- Originally, cellular networks were developed largely to provide speech for mobile phones.
  - 'Circuit switched networks'
  - Evolved from 'plain old fashioned' telephone networks
- Wi-Fi networks were developed to provide data for lap-tops & PDAs.
  - 'Packet switched networks'
  - Evolved from computer networks including Ethernet
- From beginning, cellular networks started to provide data, and Wi-Fi networks were used for speech (VoIP etc.)
- Currently, use for speech is largely saturated, but data use is expanding rapidly.

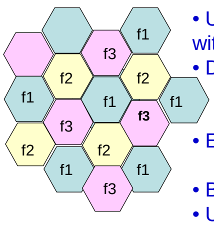
Mobile devices

- Originally, we had mobile phones for speech, lap-top computers & simple 'PDA' devices for data.
- GPS devices
- Bluetooth connections for hand-free car-phones, etc.
- Portable radios & TVs
- Digital cameras, sound recorders, mp3 players, etc...
- Now all these facilities have converged,
- Provided by a single device, e.g. a 'smart phone' or tablet.

Cellular, wi-fi, GPS & bluetooth



Cellular concept



- Use of licensed radio frequency bands with 'spatial multiplexing.'
- Divide city into small areas called **cells**
  - From 0.1 to 35 km in diameter.
  - Hexagonal shape is hypothetical.
- Each cell given a frequency band e.g. *f1*, *f2*, *f3*
- Bands re-used when cells are far away.
- Users must not transmit 'too loud'
- Frequencies must be different in adjacent cells
- 'Seamless hand-over' as user moves from cell to cell.
- To add more users, make cells smaller & reduce power.
- Reducing power makes bit-errors more likely – need FEC

Generations of mobile telecoms standards

- 0G Radio telephones (non-cellular)
- 1G (1983) Cellular analogue for voice – e.g. AMPS
- 2G (1991) Cellular digital for voice & slow data; GSM & IS95
  - 2.5G(≈1998) Introduce GPRS (56-114 kbit/s)
  - 2.75G(≈2003) Add EDGE(E-GPRS) (up to 384 kbit/s)
- 3G (≈2001) IMT2000 for speech & faster data - UMTS etc
  - 3.5G(≈2007) HSPDA (1.8-7.2 Mbit/s downlink, 384 kbit/s uplink)
  - 3.75G (≈2010) HSPA+ (downlink: 56 Mbit/s, uplink: 22 Mbit/s).
  - 3.95G (?) 3GPP-LTE, mobile-WIMAX.
- 4G (≈2011) ITU-'IMT Advanced' specification published
  - 3GPP-LTE & mobile-WIMAX currently marketed as 4G
  - But they do not really meet the spec (1Gb/s & 100 Mb/s).
  - Traditional circuit switched telephony abandoned. Now all IP.
- 5G (≈2021?) The future!

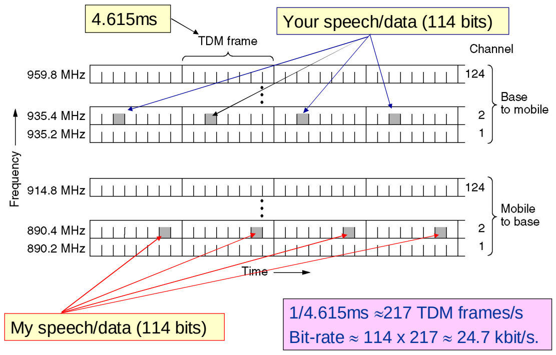
Some Acronyms

- AMPS – Advanced (analogue) mobile phone system
- GSM – (European) Global system for mobile comms
- IS95 – USA equivalent of GSM
- GPRS –General packet radio system for 2G (56-114 kb/s)
- EDGE – Enhanced GPRS (≈ 384 kb/s)
- IMT2000 – International mobile telecomms (3G standard)
- UMTS – Universal mobile telecoms system
- HSDPA – High speed downlink packet access
- HSPA+ – High speed packet access
- LTE – Long term evolution (from 3G to 4G)
- WiMAX- Worldwide Interop for Microwave Access
- ITU – International telecomms Union
- 3GPP – 3G Partnership Project (ex GSM)
- 3GPP2-3G Partnership Proj 2 (ex IS-95 & CDMA2K in USA)

Multiplexing-sharing radio spectrum

- FDMA-Frequency division multiplexed access **(0G & 1G)**
  - Each transmitter given a different ‘carrier’ frequency
- TDMA-Time division multiplexed access **(2G-GSM)**
  - Each transmitter given a regular time-slot
- CDMA-Code division multiplexed access **(2G- IS95 & 3G)**
  - Each transmitter uses same band with a unique code
- OFDMA-Orthognal frequency division multiplex access **(4G)**
  - Used with MIMO-multi input/multi output antennas
  - Each transmitter uses several ‘carrier’ frequencies at once.
  - Packetised transmission compatible with IP
- ALL use spatial multiplexing (cells) as well **(apart from 0G)**

2G-GSM-TDMA (in 900 MHz band)



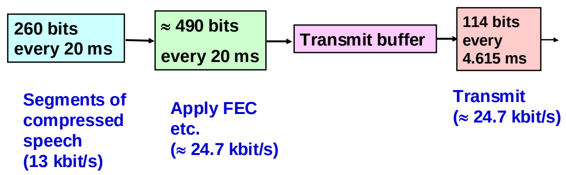
2G-GSM-TDMA observations

- Two 25 MHz channels used for 124 × 8 = 992 users.
- FDMA divides 25 MHz into 124 bands (0.2 MHz each).
- TDMA divides each band into 8 time-slots.
- Different slots for base to mob & mob to base (why?)
- 114 bit ‘packets’ with 217 ‘packets/s gives 24.7 kbit/s
- Short packets, regular slots.
- No ‘contention mode’ & little delay.
- Supports **13 kbit/s** coded speech or data, with FEC extra.
- Some capacity used for synchronisation, signalling etc.

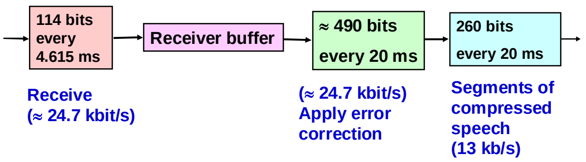
Speech transmission (2G-GSM)

- Obtain encoded segments of digitised voice by
  - Capturing analog voice, low-pass filtering, sampling & quantising.
  - Packetising into typically 20ms (160 sample) blocks
  - Applying LPC compression to reduce bit-rate to 260 bit/block (Equivalent to 13 kbit/s).
  - Applying FEC in case bit-errors occur. (Increases bit-rate to approx 24.7 kbit/s)
  - Interleaving in case bit-errors are in ‘bursts’
  - Adding info. & encrypting for security & storing in buffer
- Each time the assigned TDMA time-slot comes around,
  - Take 114 bits from the buffer.
  - Modulate them onto a sinusoidal carrier of the assigned frequency
  - Transmit them by applying the resulting voltage to an antenna.
- Continue these concurrent processes.

Buffering (2G-GSM)



Receiver-buffering (2G-GSM)



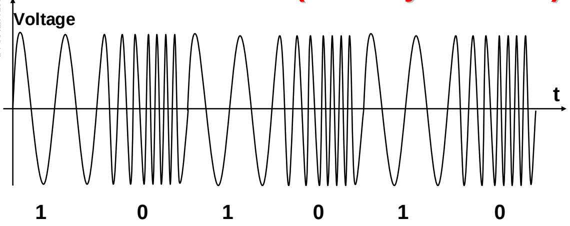
Lecture 6 COMP28512 13

Speech receiver (2G-GSM)

- In each assigned time-slot, receive assigned modulated carrier:
  - Demodulate to extract 114 bits
  - Accumulate in receiver-buffer
- At intervals of 20 ms:
  - Extract 490 bits from buffer to form FEC coded voice segment
  - Remove encryption & interleaving.
  - Apply bit-error correction & remove FEC redundancy to leave 260 bits
  - Apply LPC decoder to obtain 160 samples of speech.
  - Send samples to D to A converter, low-pass filter, amplifier & speaker.
- Continue these two concurrent processes.

Lecture 6 COMP28512 14

B-FSK modulation (used by 2G-GSM)



- Binary frequency shift keying (FSK) transmits a low freq sine-wave for 1 & a high freq one for 0.
- It is simple not very efficient but CONSTANT AMPLITUDE.
- Probably the secret of 2G-GSM's early success.

Lecture 6 COMP28512 15

CDMA (used by 3G)

- Each bit from coded signal is 'spread', e.g. to produce:

  1 = 1 0 1 0 1 1 0 0 0 1 0 1 0 1 0 1 0 1 1 1 0 1 0 1 0 1 0 1 0 1
  0 = 0 1 0 1 0 0 1 1 1 0 1 0 1 0 1 0 1 0 0 0 1 0 1 0 1 0 1 0 1 0

- Each 'bit' becomes a pseudo-random sequence of 'chips'
  - Transmitted at high chip-rate – needs wide bandwidth.
- Can recover orig signal if pseudo-random sequnce is known.
  - Otherwise transmission will be heard as noise.
  - All users transmit at the same time in same frequency band.
  - But they all use a different sequence
  - Receivers can recover each bit by a cross-correlation process.
- Has 'soft' capacity limit.
- Used by 2G-IS95 in USA and 3G everywhere.

Lecture 6 COMP28512 16

Example: CDMA coding

- User A transmits 1 & -1 volt for 'chips' 1 & 0, respectively.
  - For '1' send 1 -1 1 -1 1 1 -1 -1 -1 1 (code with 10 chips)
  - For '0' send -1 1 -1 1 -1 -1 1 1 1 -1
  - Multiply what we receive by 1 -1 1 -1 1 1 -1 -1 -1 1 & sum.
  - For '1', we get +10, for '0', we get -10.
- User B uses a different code:
  - '1' ≡ 1 1 1 1 1 -1 -1 1 -1 -1 '0' ≡ -1 -1 -1 -1 -1 1 1 -1 1 1
  - Multiplying by user B's code & summing gives +10 or -10.
  - Multiplying by user A's code & summing gives 0 (both cases)
- If A & B transmit together, say '1' & '0', voltages add.
  - We receive 0 -2 0 -2 0 2 0 -2 0 2
  - Mult by A's code & add gives +10 ≡ '1'
  - Mult by B's code & add gives -10 ≡ '0'.

Lecture 6 COMP28512 17

Cocktail party analogy

- Partners in couples are talking to each other in a large bar.
- TDMA: Each speaker gets a turn to speak for a short time. He/she must then stop to let another person speak. More than one speaker are never allowed to talk at the same time unless they are far away and will not hear each other.
- CDMA: Any speaker can talk at any time but using a different language. Each listener can only understand the language of a partner. Because of the differences in languages, listeners can focus on what their partners are saying and other conversations sound like noise or 'babble'.
- As more & more people enter the bar, the babble gets louder and listeners may no longer be able to make out what their partners are saying without getting closer to them. This is like CDMA cells decreasing in size as the number of active users increases. It is called 'cell breathing'.
- FDMA: Can't think of a way of illustrating FDMA without being silly.

Lecture 6 COMP28512 18

OFDM & MIMO (used by WiFi & 4G)

- OFDM uses many sinusoidal carriers simultaneously.
- Data spread out among them so that if some are not received, data can be obtained from the others.
- Sorry, no time to say more on OFDM.
- MIMO can double the capacity of a radio channel by having 2 transmit and 2 receive antennas.
- More on this later.

Circuit & packet switching

- Since invention of telephone, speech was circuit switched
- Originally this meant connecting wires for analogue trans
- Concept continued into digital/mobile systems right up to 4G.
- Data networks were always packet switched.
- With 4G, all speech & data will be packet switched & conveyed by IP.

- Frequency bands in UK: 900, 1800, 2100 MHz
- From Feb'13 (UK auction): 800 (ex-TV) & 2600 MHz

4G ITU-'IMT Advanced' specification

- Original goals for 4G were:
  - Up to 100 Mbit/s for high mobility access
  - Up to 1 Gbit/s for low mobility/nomadic access
  - All-IP packet switched network.
  - Smooth handover across different networks
  - High spectral efficiency with dynamic sharing of network resources.
- Two potential 4G technologies proposed by Sept 2009:
  - 3GPP-LTE-Advanced (due 2010 - still waiting)
  - IEEE 802.16m (enhanced mobile WiMAX)
  - No more since
- Achievements to date:
  - LTE: 28 or 42 Mbit/s down, 22 Mbit/s upstream (actual)
    (projected: 300 Mbit/s down, 75 Mbit/s up)
  - WiMAX: 120 Mbit/s down, 60 Mbit/s upstream
  - These figures may be misleading; take them with 'a pinch of salt'

Questions for us

1. A source holds ten minutes of music encoded using MP3 at 128 kbit/s. How long might it take to download it using LTE bit-rate of 42 Mb/s?
   [Answer: 1.83 s (not bad?)]
2. A 10 minute video-clip is encoded using MPEG-1 at 1.2 Mbit/s. How long might it have taken to download it using 2G-GPRS at 114 kbit/s?
   [Ans: 6316 s, i.e. >100 minutes (bad)]
3. How long for Q2 if 4G standard is ever realised?
   [Ans: At 100 Mb/s, it will take 7.2 s]
4. If a 10 minute 1.2 Mb/s video-clip is reaching you at 1 Mb/s, how much should you buffer before starting to watch it?
   [Ans: Takes 10x60x1.2 s = 12 mins to download all of it.
   Buffer 2 mins, to make sure that you download all 10 mins of video-clip within a further10 mins]

3GPP-LTE

- Project to evolve from 3G-UMTS towards 4G.
- New standard: '3GPP-LTE-advanced' was promised by end of 2010.
- This was expected to achieve the 4G goals.
- New developments include:
  + IP for all voice (VoIP) & data (with seamless handover)
  + Enhanced precoding & forward error correction (FEC)
  + New radio transmission techniques (OFDMA & SC-FDMA)
  + Multiple antennas (MIMO)
  + Flexible spectrum usage, better security
- Failed to meet 4G specification, but 'aspires' to do so.
- So can be marketed as '4G'

mobile-WIMAX

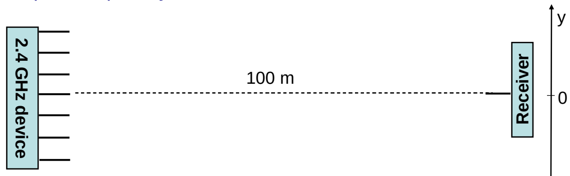
- Also failed to achieve the 4G specification.
- But 'aspires' to do so, like LTE.
- Marketed as 4G in USA & elsewhere (not in UK)
- Details later.

5G: the future

- 5G (≈2021?): No projects yet, only ideas such as:
  - Beam-division multiple access
  - Relays with group co-operation
  - Higher spectral efficiency by cognitive (smart) radio.
  - Mobile IPv6 & 'flat IP'
  - Higher energy efficiency
  - Massive Dense Networks
  - Option of direct device-to-device (D2D) comms
  - Support for 'Internet of things'
  - etc.
  - (This is your world)

Beam division multiple access (for 5G)

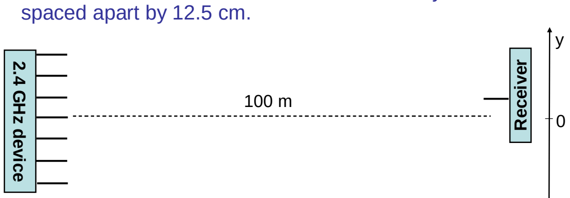
- A single antenna transmits with equal power in all directns.
- Consider a 2.4 GHz Wi-Fi device with an array 7 antennas spaced apart by 12.5 cm.



- A single antenna receiver is placed 100 m away as shown.
- It may be moved up or down the y direction.
- Neglecting path loss, received amplitude is plotted next.

Beam division multiple access (for 5G)

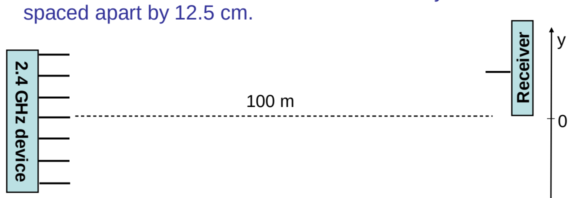
- A single antenna transmits with equal power in all directns.
- Consider a 2.4 GHz Wi-Fi device with an array 7 antennas spaced apart by 12.5 cm.



- A single antenna receiver is placed 100 m away as shown.
- It may be moved up or down the y direction.
- Neglecting path loss, received amplitude is plotted next.

Beam division multiple access (for 5G)

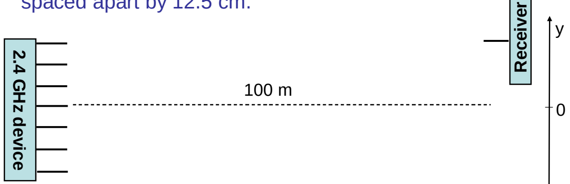
- A single antenna transmits with equal power in all directns.
- Consider a 2.4 GHz Wi-Fi device with an array 7 antennas spaced apart by 12.5 cm.



- A single antenna receiver is placed 100 m away as shown.
- It may be moved up or down the y direction.
- Neglecting path loss, received amplitude is plotted next.

Beam division multiple access (for 5G)

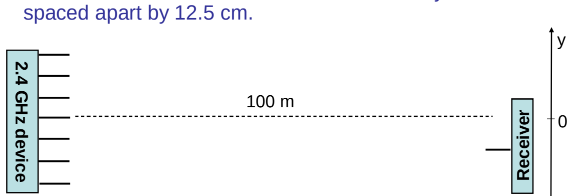
- A single antenna transmits with equal power in all directns.
- Consider a 2.4 GHz Wi-Fi device with an array 7 antennas spaced apart by 12.5 cm.



- A single antenna receiver is placed 100 m away as shown.
- It may be moved up or down the y direction.
- Neglecting path loss, received amplitude is plotted next.

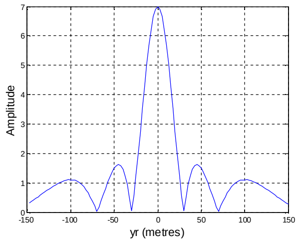
Beam division multiple access (for 5G)

- A single antenna transmits with equal power in all directns.
- Consider a 2.4 GHz Wi-Fi device with an array 7 antennas spaced apart by 12.5 cm.



- A single antenna receiver is placed 100 m away as shown.
- It may be moved up or down the y direction.
- Neglecting path loss, received amplitude is plotted next.

Beam-forming result



- Notice the main-lobe, side-lobes & zeros.
- A receiver placed as shown on slide gets high signal as all 7 transmission add ≈ 'in phase'.
- Move it up or down by 30 m, & it gets almost nothing.
- Move it further & signal returns but not so high.

•Transmitter can 'target' a particular receiver by beam-forming.

•Other receivers can be nulled out or sent a reduced signal

Beam-forming demo

```
c=3e8;  % Speed of light in m/s
F = 2.4e9; % Freq in Hz (2.4 GHz)
lambda = c / F;  % wavelength in meters
Fs = 20*F;  % Sampling freq (Hz)
% Positions of 7 elements of transmitting antenna:
xa = [0 0 0 0 0 0 0];
ya = [-1.5*lambda  -lambda -lambda/2   0  lambda/2  lambda 1.5*lambda];
xr = 100;  % horiz distance of receiver from transmitter
for inc=1:120,
   yr(inc)=20*lambda*(inc-60); % dist of receiver from (0,yr)
for i=1:7,
   dist=sqrt( (yr(inc)-ya(i))^2 + (xr-xa(i))^2);
   delay(i)= dist/c;  % delay in seconds
end;
%Assume transmit antenna signal is cos(2*pi*F*t)
for n=1:40,
   rsig(n)=0;
   for i=1:7, rsig(n) = rsig(n) + cos(2*pi*F*(n/Fs+delay(i))); end;
end; % n
Amp(inc) = max(abs(rsig));
end;
figure(1); plot(yr, Amp); grid on;
xlabel('yr (metres)','fontsize',14);  ylabel('Amplitude', 'fontsize',14);
```


Beam-division MA (concluded)

- Also, can have receiver with 7 antennas that will target a particular transmitter – it will only hear that one.
- This is better than cellular concept for spatial multiplexing.
- In fact, it is a little like having wires.
- Researchers are exploring this concept for next generation (5G) mobile systems.
- (N.B. Beams can be digitally 'steered' by inserting delays into feed to the multiple antennas. Sorry, no time for this.)

Group Cooperative Relaying (for 5G)

- When a source transmits data to a destination, another user who hears the transmission can act as a 'relay'.
- The relay also forwards the message to the destination where both received signals may be combined.
- As the 2 transmissions will have different paths, this gives diversity.
- Cooperative diversity can be performed two ways.
  1. Amplify & forward
     - also amplifies noise.
  2. Decode & forward
     - Relay station decodes & recodes the transmission,
     - Then forwards it to the destination.
     - Relay node can add error correcting coding.

Cognitive radio (for 5G)

- Currently radio transmissions to/from mobile systems confined to pre-assigned spectral bands; e.g. 2.4-2.5 GHz.
- This is very inflexible & inefficient.
- Systems using cognitive radio could be designed to search for & use best available wireless channels that have spare capacity.
- Must adapt their transmission or reception parameters to the channel .
- This is a form of dynamic spectrum management.

Mobile IPv6 (for 5G)

- With mobile IP, each mobile device has a home IP address and a 'care of 'address.
  – When any other device sends a packet to this home IP address, a server forwards it to the device.
  – The server also returns a packet to the other device to inform it of the correct address for any future communication.
- Mobile IP is not used by 3G cellular systems when Internet users migrate between cells.
  – There is a different DLL handover mechanism.
  – However, mobile IP is used for accessing data services.
- Because of the many addresses likely to be generated, IPv6 is needed for mobile systems.
  – It is proposed to encapsulate both home & care-off addresses within each IPv6 address.
- A goal of 5G is to adapt all mobile networks to a single worldwide standard based on IPv6 for control, packet data, video and voice.

Energy efficiency (for 5G)

- Currently, networks are designed to cater for peak load.
- If the load decreases, then the coverage of some cells can be allowed to increase & others can be turned off.
- Network can adapt to current user pattern.
- Aim to preserve energy supplied to base-stations.
- Without causing transmit/receive power needed by mobile devices to increase significantly
  - e.g. because they have to transmit further
  - or receive from further away.

Wi-Fi (IEEE802.11 standard)

- Provides wireless access to IP computer networks via access points.
  - Internet protocol (IP) is most used addressing & data communication mechanism for networks linking computers
- Essentially 'wireless Ethernet'
  - Ethernet is most commonly used standard for wired LANs.
- Use of unlicensed radio frequency bands* over short distances within 'hot-spots' (homes, offices, cafes, etc.)
- Primarily designed for data.
- Packet based (like Ethernet)
- Faster & cheaper than cellular for data.

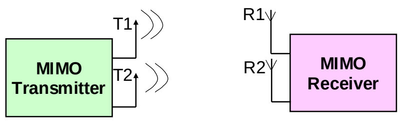
* License-free bands: 2.4 (2.4-2.5), 5 (4.9 – 5.8) & 60 GHz

IEEE802.11 Wi-Fi versions

Version	Date	Band (GHz)	Channel (MHz)	Bit-rate (Mbit/s)	MIMO
a	1999	5	20	54	no
b	1999	2.4	20	11	no
g	2003	2.4	20	54	no
n	2009	2.4/5	20	72/150	4
ac	Jan'14	5	20-160	up to 866	8
ad (wiGig)	Dec'12	60	2160	up to 6192	no
etc					

MIMO: multiple input-multiple output

- Uses more than one transmitter antenna & same number of receiver antennas to increase capacity of a wireless link.



- Assume 2 transmit antennas T_1 & T_2 & 2 receive antennas R_1 & R_2
- T_1 & T_2 may be sending 2 completely different signals
- R_1 will receive sum of signals from T_1 & T_2 each modified by the channel in different ways. Similarly for R_2.

MIMO (cont)

- Each signal reaches receiver by slightly different path causing different frequency dependent loss and delay.
- If T_1(f) & T_2(f) are FFT of T_1(t) & T_2(t) respectively:

$R_1(f) = h_{11}(f)\, T_1(f) + h_{12}(f)\, T_2(f)$

$R_2(f) = h_{21}(f)\, T_1(f) + h_{22}(f)\, T_2(f)$

- In matrix form:

$$\begin{bmatrix} R_1(f) \\ R_2(f) \end{bmatrix} = \begin{bmatrix} h_{11}(f) & h_{12}(f) \\ h_{21}(f) & h_{22}(f) \end{bmatrix} \times \begin{bmatrix} T_1(f) \\ T_2(f) \end{bmatrix} \quad \text{or} \quad \underline{R} = H \times \underline{T}$$

- For each *f*, solve simultaneous equations to obtain $\underline{T} = H^{-1} \times \underline{R}$

$\therefore T_1(f)$ & $T_2(f)$ can be deduced from $R_1(f)$ & $R_2(f)$.

- $h_{11}(f)$, $h_{12}(f)$, etc are complex functions of frequency.
- Determined by channel soundings.

MIMO (simple example)

$R_1(f) = .2 \times T_1(f) + .3 \times T_2(f)$

$R_2(f) = .1x\, T_1(f) + .2x\, T_2(f)$

- In matrix form:

$$\begin{bmatrix} R_1(f) \\ R_2(f) \end{bmatrix} = \begin{bmatrix} 0.2 & 0.3 \\ 0.1 & 0.2 \end{bmatrix} \times \begin{bmatrix} T_1(f) \\ T_2(f) \end{bmatrix} \quad \text{or} \quad \underline{R} = H \times \underline{T}$$

- For each *f*, solve simultaneous equations to obtain:

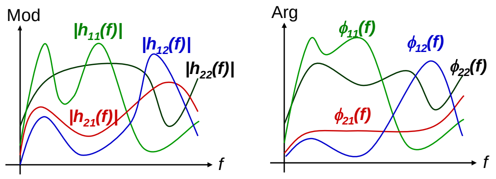
$T_1(f) = 20xR_1(f) - 30xR_2(f)$; $T_2(f) = 20 \times R_2(f) - 10 \times R_1(f)$

$\therefore T_1(f)$ & $T_2(f)$ can be separated at receiver.

- Invert the FFT to get T_1 & T_2 in time-domain.
- Two different signals over one channel !! Doubles capacity.

MIMO (finally)

- Possible mods & args of channel functions:



- Another example of frequency-domain processing
- If R_1(f) & R_2(f) are FFT of R_1(t) & R_2(t), must solve for $T_1(f)$ & $T_2(f)$ at all FFT frequencies
- Then inverse-FFT the result to get T_1(t) & T_2(t).

Lecture 6 COMP28512 43

Question for us

- With a perfect channel with no reflections or channel loss, we may find that $h_{11}(f) = h_{12}(f) = h_{21}(f) = h_{22}(f)$ at all (or some) frequencies.

How can we solve $T = H^{-1}xR$ to deduce the two different transmitted signals T_1 & T_2 ?

[Ans: We cannot because matrix H will be singular.

To put it another way, the 2 equations:

$R_1(f) = h_{11}(f)\ T_1(f) + h_{22}(f)\ T_2(f)$

$R_2(f) = h_{21}(f)\ T_1(f) + h_{22}(f)\ T_2(f)$

become identical. Only have one equation for 2 unknowns.

So MIMO needs reflections & multipath transmission to work.

When it works, it doubles bit-rate capacity of our wireless channel]

Lecture 6 COMP28512 44

WIMAX (IEEE802.16)

- "WiFi on steroids"
- Usage at much greater distances than Wi-Fi.
- More similar to Wi-Fi than to cellular telephony.
- Originally for last mile 'backhaul' broadband links, as alternative to cable.
- Mobile WiMAX is alternative to GPP-LTE for cellular phones.
- WiMax handsets, similar to cellular smart-phones, have been produced.

Lecture 6 COMP28512 45

GPS

- GPS receiver calculates its position from timing signals sent by GPS satellites 20,200 km above the Earth (not in geo-stationary orbit)
- 24 satellites arranged in 6 different orbital planes, each inclined 55^{O} to equator.
- Each satellite continually transmits messages that include
  - Exact time of message
  - Satellite position at time of message
- Receiver determines transit time of each message
- Computes distance to each satellite (x by speed of light).
- One satellite not enough; 4 or more needed ideally.
- Receiver must solve 'navigation equations'
- Also computes time to accurately of ≈ 0.3 µs.
- Useful for synchronization of cell-phone base stations.

Lecture 6 COMP28512 46

Bluetooth

- Radio standard for exchanging data over short distances
- Same frequency band as wi-fi.
- Wireless alternative to data cables.
- Uses packets and 'frequency hopping'.

Lecture 6 COMP28512 47

Hedy Lamarr invented 'freq hopping'

- She invented it as a form of encryption.
- She was an Austrian born actress who met Adolf Hitler & was the first actress to remove all her clothes in a movie.
- She was awarded a patent for radio technology used against the Germans in WW2

Lecture 6 COMP28512 48

Implemented by mobile devices

- Radio/comms functionality
  - access cellular network, wi-fi, GPS & BlueTooth
  - transmit / receive user data
  - manage radio resources & connections
  - processing by DSP cores
- Human interface
  - microphone, loudspeaker, display & keyboard
  - processing by RISC cores e.g. ARM
- Source processing: LPC, MP3, JPEG, MPEG, etc.
- Interleaving, FEC, security etc.

Lecture 6 COMP28512 49

Summary

- Evolution of mobile network for telephony & data
- Generations of mobile telecoms standards.
- Cellular concept & spatial multiplexing.
- Multiplexing with FDMA, TDMA, CDMA, OFDMA
- Aspirations of 4G – not yet achieved
- 3GG-LTE & WiMAX,
- Projections to 5G (your future)
- WiFi, Bluetooth, GPS, etc
- MIMO explained
- Linear prediction encoder (removed to WS1).

Lecture 6 COMP28512 50

Twenty Questions for you

1. With respect to 2G technology, what contributed to the greater success of the European GSM standards in comparison to IS95 in the USA?
2. What advantages came from the change to digital (2G from 1G)
3. What is frequency shift keying (FSK) as used by 2G-GSM?
4. Why was it easier to update IS95 (& later versions) to 3G tech?
5. If IEEE802.11 is 'wi-fi' what is IEEE802.3 called?
6. What are the 'ISM' bands & what are they used for?
7. How would you define 'nomadic'?
8. How do cells 'breath' (see refs)
9. What is cellular 'hand-over' & why should it be seamless?
10. Why are geostationary satellites good for broadcasting but not so convenient for mobile computing & telephony.
11. What do the following have in common and why?: [Brain of Britain question!]
    (a) a commonly used spectral spreading technique,
    (b) a piano, (c) Adolph Hitler and
    (d) the first actress ever to appear nude on film.

Lecture 6 COMP28512 51

Twenty Questions (cont)

12. What is meant by vector-quantisation as used by CELP coding?
13. How does a DSP microprocessor differ from a RISC and a general purpose processor?
14. Why are DSP processors used in mobile phones and why are they generally programmed in fixed point arithmetic?
15. On slide 4, why do APs have 2 antennas spaced ≈12.5 cm apart?
16. What is multi-carrier modulation?
17. Why is FEC coding more important for mobile systems than for wired comms?
18. What is the difference between vertical & horiz handover?
19. As each mobile device has a MAC (PHY) address, why do we need IP addresses?
20. How long might it take to upload an uncompressed 8 megapixel colour photo from your mobile phone via 3G-HSPA+?

Lecture 6 COMP28512 52