

Telcom 2720 Cellular and Wireless Networks

David Tipper
Associate Professor
Telecommunications Program
University of Pittsburgh

dtipper@mail.sis.pitt.edu
<http://www.sis.pitt.edu/~dtipper/2720.html>
Slides 1



Course Goals

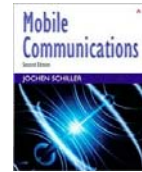


- Provide students a understanding of the structure, system aspects and protocols of cellular and wireless networks. The focus in on the generations of cellular networks, WMANs, WLANs, and WPANs.

Text and Grading



- Text: Mobile Communications 2nd edition, Jochen Schiller, Addison Wesley
- Principles of Wireless Networks A Unified Approach, K. Pahlavan and P. Krishnamurthy, Prentice Hall, 2002.
- Overview of wireless network architectures
 - Will post many links to papers to fill in on newer developments
- Grading
 - Homework + Labs (2 or 3 labs) 25%
 - Midterm 25%
 - Final Exam 30%
 - Term Project 20%
 - Group or individual project that involves developing, deploying, researching a wireless network technology
 - Past Projects include
 - Evaluation of battlefield WLAN implementation
 - WiMAX QoS planning techniques
 - Comparative evaluation of smart antenna techniques
 - Ad hoc extensions of cellular networks for disaster/fault recovery
 - Regulatory issues for software/cognitive radios
 - Health issues of wireless technology



Telcom 2720

3



Course Outline



- Introduction
 - Mobile communication systems issues, system structure of wireless networks, safety
- Wireless communication fundamentals
 - Propagation, Modulation and Coding, Frequency reuse. Traffic eng.
- First Generation (1G) Cellular: AMPS
- Intersystem Operation + Mobility Management
 - Location tracking and Paging, Handoff
- Second Generation Cellular:
 - Vocoding
 - GSM, (Ch 7)
 - IS-95 (Ch 8)



Telcom 2720

4



Course Outline



- 2.5G Cellular: Wireless Data Services
 - GPRS, Edge
 - cdma2000 1x-rtt
- 3G Cellular:
 - Structure, protocols and advance services
 - UMTS
 - Cdma 2000 1X-EVDO and extensions
- Satellite Networks
- Location Based Systems/Services
- Wireless Local Area Networks
 - 802.11, infrastructure based, hybrid WLAN and cellular
- Wireless Personal Area Networks
 - 802.15 (Bluetooth, Zigbee)
- Wireless MANs
 - 802.16 WiMAX



Telcom 2720

5

Mobile vs. Wireless



- Wireless Communication System:
 - Any electrical communication system that uses a naturally occurring communication channel, such as air, water, earth.
- Mobile and Wireless are not interchangeable



Wireless vs. Mobile

- | | |
|---|---|
| x | x |
| x | ✓ |
| ✓ | x |
| ✓ | ✓ |

Examples

- stationary computer, pay phone
- calling card, call forwarding
- wireless local loop
- cell phone, laptop with WLAN



- Mobile wireless communication systems focus
 - Communicate over the air via radio-waves
 - Support some form of user mobility
- Examine how they are different from wired networks



Telcom 2720

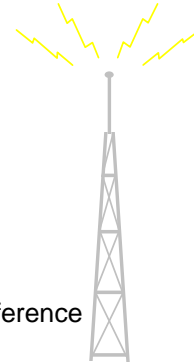
6

Wireless Issues



- **Wireless link implications**

- *communications channel* is the air
 - poor quality: fading, shadowing, weather, etc.
 - data rate and coverage vary
- *regulated* by governments
 - frequency allocated, licensing, etc.
- *limited bandwidth*
 - low bit rate, frequency planning and reuse, interference
- *power issues*
 - Power levels regulated (safety issue), conserve mobile terminal battery life
- *security issues*
 - wireless channel is a **broadcast** medium!



Telcom 2720

7



Mobility Issues



- **Mobility Types**

- **User mobility** : user can access network while mobile
 - must handoff calls/connections in progress as user moves
 - track users as they move so they can receive info/calls
- **Service mobility**: user's services follow them
 - Need to have authentication and services follow user

- **Degree of Mobility**

- Geographic range
 - ranges from a house/apartment to worldwide
- Speed
 - ranges from stationary to bullet train
 - cordless phone vs. cell phone

- **Mobility → portable device**



Telcom 2720

8

Device Issues



• Mobile Device Issues

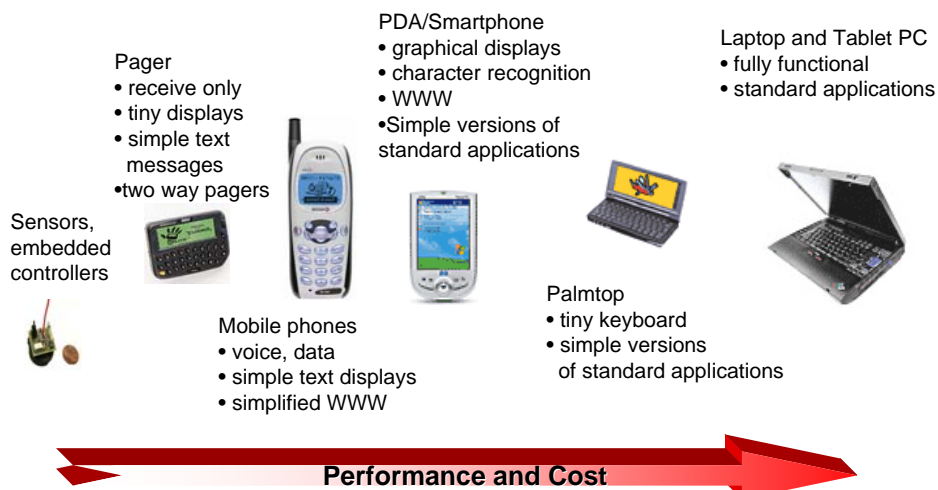
- Portability
 - Device and accessories size and weight
- Usability
 - User characteristics (size, dexterity, knowledge, etc.)
 - Environment characteristics (Temperature, degree of mobility, etc)
 - Device Characteristics
 - startup time
 - data integrity and security
 - cpu speed and memory size
 - power supply
 - user interface (keypad, stylus, voice, etc.)
 - Functionality (standalone, network dependent)
 - Connectability (always, partial, never)
- In general have a limited power supply, user interface and speed compared to stationary device



Telcom 2720

9

Mobile Devices



Telcom 2720

10

Wireless Networks



– Wireless Wide Area Networks (WWANs)

- Cellular Networks :
 - GSM, cdmaone (IS-95), UMTS, cdma2000 EVDO
- Satellite Networks:
 - Iridium, Inmarsat, GPS, etc.



– Wireless Metro Area Networks (WMANs)

- IEEE 802.16 WiMAX

– Wireless Local Area Networks (WLANs)

- IEEE 802.11, a, b, g, etc. (infrastructure, ad hoc)

– Wireless Personal Area Networks (WPANs)

- IEEE 802.15 (Bluetooth), IrDa, Zigbee, sensor, etc.

Telcom 2720

11



Wireless Networks

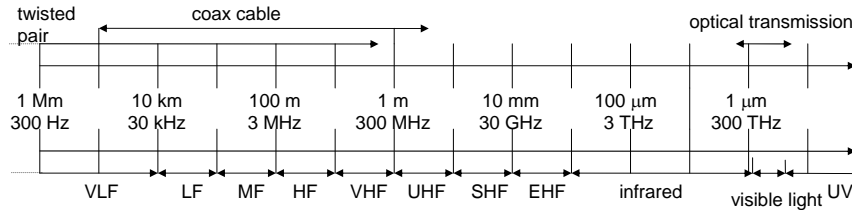


Network	Geographic Coverage	Typical Throughput	Standards
WWANs	National, Continent wide Worldwide	2G: 9.6 – 45 Kbps, 2.5G: 50 -300 Kbps 3G : 50kbsp- 2Mbps 3.5G: .1 – 10 Mbps Satellite – 9.6 – 200Kbps	2G: GSM, cdmaone 2.5G: GPRS, cdma 2000 1X-rtt 3G: UMTS, cdma2000 1x-EDVO 3.5G: HSPDA
WMANs	Metro, suburb, campus 1-15 km	100 Mbps – 10Gbps	IEEE 802.16
WLANs	In building, campus wide, subdivision wide, Range ~ 100 M per AP	1-106 Mbps	IEEE 80211a, b, g, etc.
WPANs	5-10 M around device	.1 – 1Mbps	IEEE 802.15 IrDa, BlueTooth, Zigbee

Telcom 2720

12

Frequencies for Communication



- Frequency and wavelength: $\lambda = c/f$
- Wavelength λ , speed of light $c \cong 3 \times 10^8 \text{m/s}$, frequency f in Hz
- VLF = Very Low Frequency UHF = Ultra High Frequency
- LF = Low Frequency SHF = Super High Frequency
- MF = Medium Frequency EHF = Extra High Frequency
- HF = High Frequency UV = Ultraviolet Light
- VHF = Very High Frequency
- VHF-/UHF-ranges for cell phones
- SHF and higher for directed radio links, satellite communication
- WLANs, WMANs, use frequencies in UHF to SHF spectrum

Telcom 2720



Radio Frequency Bands



Table 3-5 Radio frequency bands

Band	Frequency	Common Uses
Very Low Frequency (VLF)	10 KHz to 30 KHz	Maritime ship-to-shore
Low Frequency (LF)	30 KHz to 300 KHz	Cordless telephones
Medium Frequency (MF)	300 KHz to 3 MHz	AM radio
High Frequency (HF)	3 MHz to 30 MHz	Short wave radio, CB radio
Very High Frequency (VHF)	30 MHz to 144 MHz 144 MHz to 174 MHz 174 MHz to 328.6 MHz	TV stations 2-6, FM radio Taxi radios TV stations 7-13
Ultra High Frequency (UHF)	328.6 MHz to 806 MHz 806 MHz to 960 MHz 960 MHz to 2.3 GHz 2.3 GHz to 2.9 GHz	Public safety Cellular telephones Air traffic control radar WLANs (802.11b)
Super High Frequency (SHF)	2.9 GHz to 30 GHz	WLANs (802.11a)
Extremely High Frequency (EHF)	30 GHz and above	Radio astronomy

Telcom 2720

14

Licensed Vs. Unlicensed



- Licensed Spectrum
 - need to buy right to use spectrum allocation in a specific geographic location from the government (e.g., AM/FM radio)
 - Prevents interference – licensee can control signal quality
- Unlicensed spectrum
 - Anyone can operate in the spectrum (e.g. ISM band for WLANs) but must maintain proper behavior in spectrum (max power level and frequency leakage, etc.)
 - Can have interference problems

Licensed	Unlicensed
Guaranteed access	Fast Rollout
Better coverage and quality	Coverage and quality inconsistent
Higher barriers for entrance	More worldwide options

Telcom 2720

15



Frequency Allocations



	Europe	USA	Japan
WWANs Licensed	Cellular: 453-457MHz, 463-467 MHz; PCS: 890-915 MHz, 935-960 MHz; 1710-1785 MHz, 1805-1880 MHz 3G: 1920-1996 MHz 2110-2186 MHz	Cellular 824-849 MHz, 869-894 MHz; PCS 1850-1910 MHz, 1930-1990 MHz;	Cellular 810-826 MHz, 940-956 MHz; 1429-1465 MHz, 1477-1513 MHz 3G 1918.1-1980 MHz 2110-2170 MHz
WMANs Licensed	IEEE 802.16	IEEE 802.16	IEEE 802.16
Unlicensed	3.4-3.6 GHz SAME as WLANs	2.5 – 2.6 GHz, 2.7-2.9GHz Same as WLANs	4.8-5 GHz Same as WLANs
WLANs Unlicensed	IEEE 802.11 2400-2483 MHz 5.7-5.825 GHz HIPERLAN 1 5176-5270 MHz	IEEE 802.11 2400-2483 MHz (b, g) 5.7 – 5.825 GHz (a)	IEEE 802.11 2471-2497 MHz (b, g) 5.7-5.825 GHz (a)
WPANs Unlicensed	IEEE 802.15 2400-2483 MHz	IEEE 802.15 2400-2483 MHz	IEEE 802.15 2471-2497 MHz

Telcom 2720

16

WWANs



- **Mobile phone systems**

- Support communication to mobile users via wireless radio channel
- Fastest growing technical device EVER!
 - Nokia sold over 120 million phones last year!
 - More cell phones than wired phones
 - More internet capable cell phones than PCs
- Variety of systems and standards:
 - Analog 1G : NMT, AMPS, TACS
 - Digital 2G: GSM, IS-95b (cdmaone),
 - 3G: UMTS, cdma 2000
- Scope of services and coverage areas growing
 - SMS, WebPhones, MMS, laptop data, etc.
 - Focus now on **wireless data** and *location aware services*



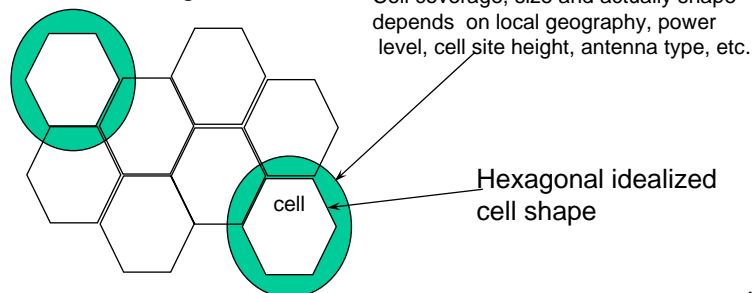
Telcom 2720

17

Cellular Network Architecture



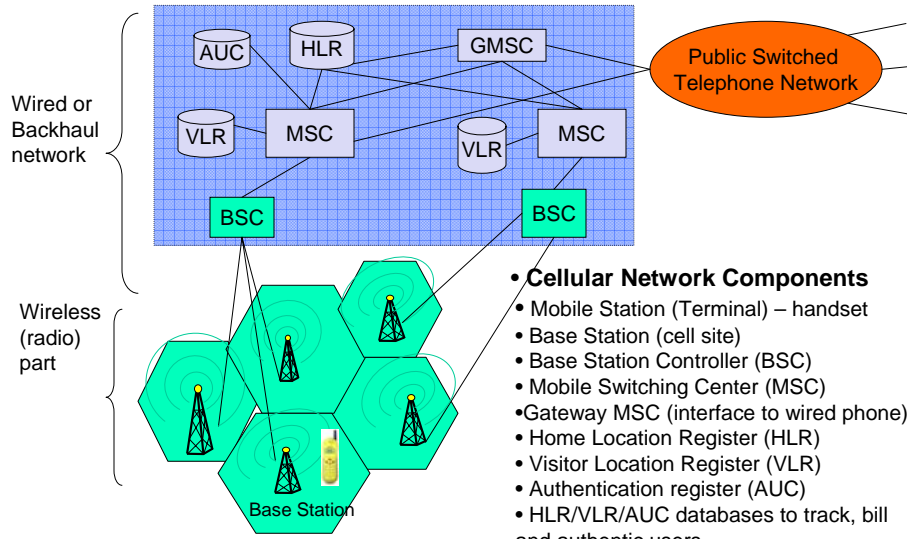
- **Cell** : Area covered by 1 radio tower unit (base station)
- **Cellular Systems:**
 - provide wireless coverage to a geographic area with a set of slightly overlapping cells. Use a set of low power radio stations to provide coverage, each cell has different set of frequencies or codes, support handoff of mobile from one cell to another, track mobile for incoming call



Telcom 2720

18

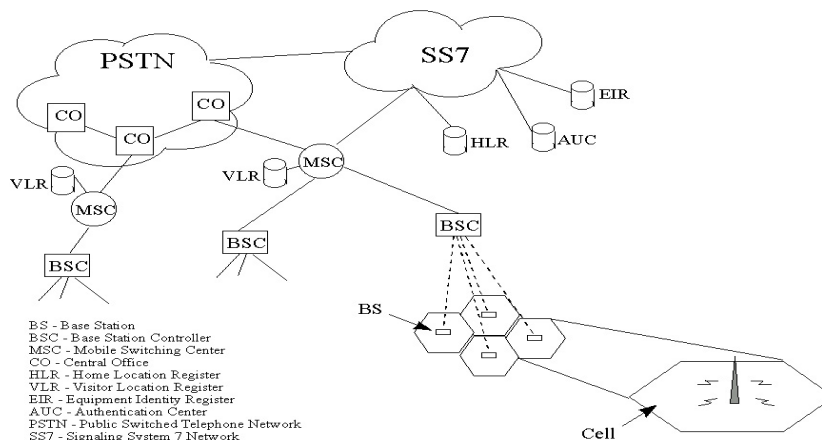
Cellular Network Architecture



Telcom 2720

19

2G Cellular Network Architecture



Telcom 2720

20

Cell Phone Market



Telcom 2720

21

• Stratification of market

- Teenage
- Safety/children
- Business – low end
- Business – high end
- Families
- Luxury

• Improvements in

- display technology
- memory
- cpu speed

• **Smaller devices greater functionality** → merger with other portable devices or accessories

2.5/3G/WLAN Mobile Devices



- More Internet-friendly interface
 - Wide, color screens
- More flexible to support new applications
 - Voice
 - Video telephony capabilities
 - Web browsing
 - Web Games
 - Electronic postcards
 - Location-based services
 - Streaming applications
- Various I/O modes/interfaces
 - Keypad,
 - voice recognition,
 - character recognition,
 - pen based, etc.



Telcom 2720

22

Handset Market



- Top Ten Phones in US during 1/01-10/30/07
 - Motorola RAZR V3
 - Motorola RAZR V3m
 - LG VX8300
 - Apple iPhone
 - LG Chocolate VX8550/8500
 - Motorola MOTOKRZR K1m
 - Samsung SGH-A707
 - LG VX5300
 - Sanyo Katana II
 - Motorola V323i/V325i



- Still a wide variety of phones and capabilities – high end PDA type phones minority

Telcom 2720

23



Base Stations

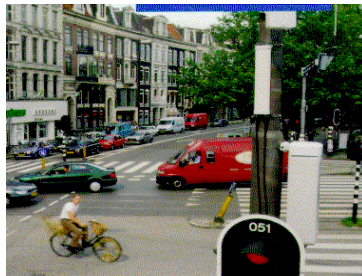


- Base Station (BS)

Provides radio channels between mobile units and network

Pico-cells : (indoor – 0.5 Km) support 8-20 channels

micro-cells: (outdoor – 0-1 Km), macro-cells: (1-30 Km)



Telcom 2720

4

Base Stations



- Base Transceiver Station (BTS) - houses radio units



Telcom 2720



25

Base Station Controller



- **Base Station Controller (BSC)**
Manages a cluster of BS, channel assignment, handoff, power control, some switching, etc



Telcom 2720

26

Mobile Switching Center



- Mobile Switching Center (MSC) (MTSO)
 - Provides switching functions , coordinates location tracking, call delivery, handoff, interfaces to HLR,VLR, AUC, etc..
 - Size of central office switch



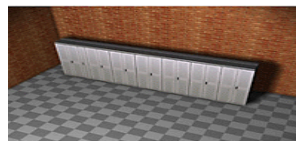
Telcom 2720

27

HLR/VLR



- Home Location Register (HLR)
 - Specialized database server contains billing info, service profile and general location of a mobile user (one per service provider or one per section of country)
 - Visitor Location Register (VLR) similar to HLR contains location of users and their service profile of all users in a metro type area (one per MSC)



Telcom 2720

28

WWANs



- Over 3500 Satellites in use today - industry overall revenues of \$2.3 billion in 2004
- Telecommunications
 - global telephone connections
 - backbone for global networks
 - connections for communication in remote places or underdeveloped areas
 - global mobile communications
- Other Applications
 - weather
 - radio and TV broadcast satellites
 - Earth observation (climate change, agricultural, etc.)
 - military: surveillance, imaging, intelligence, early warning
 - Navigation and localization: aeronautic, nautical, etc., (e.g., GPS, NavStar)

} being replaced by fiber optics

WWANs



- Satellites
 - Older technology from the 60's – over 3500 satellites in use today
 - Applications
 - Telephony/Internet access in remote areas
 - (ocean, polar regions, mountains, backup communication for disasters, etc)
 - weather
 - radio and TV broadcast satellites
 - earth observation (climate change, agricultural, etc.)
 - military: surveillance, imaging, intelligence, early warning
 - navigation and localization: aeronautic, nautical, etc., (e.g., GPS, NavStar)



Satellite Basics



• Components

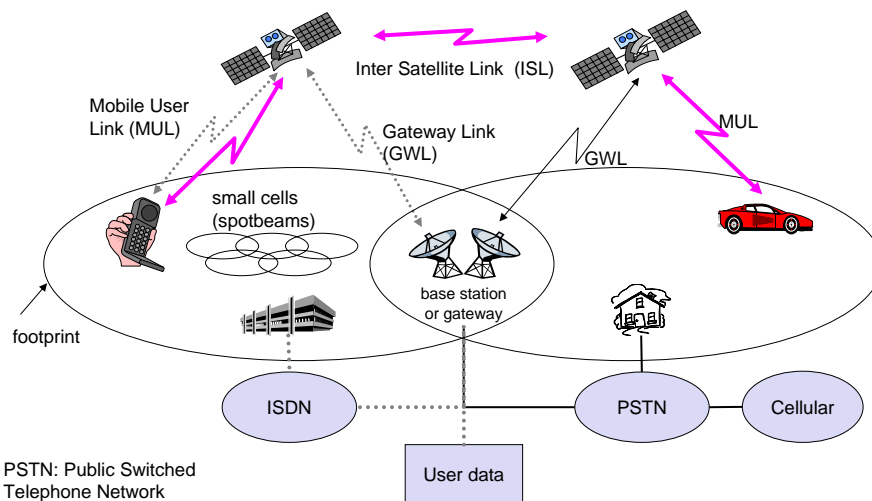
- Earth (ground) Stations – antenna systems on or near earth
- Uplink – transmission from an earth station to a satellite
- Downlink – transmission from a satellite to an earth station
- Typically separated frequencies for uplink and downlink (FDD)
- Transponder – electronics in the satellite that convert uplink signals to downlink signals
 - transparent transponder: only shift of frequencies (Bent Pipe)
 - regenerative transponder: additionally signal regeneration and formatting) Processing Satellite



Telcom 2720

31

Typical Satellite System



Telcom 2720

32

Satellite Classification



- Can Characterize Satellites on variety of Factors
- Frequency:
 - Spectrum
- Orbit:
 - Height: (GEO, HEO, MEO, LEO)
 - Pattern: elliptical vs. circular, inclination, etc.
- Multiple Access Method:
 - TDMA, FDMA, CDMA
- Satellite Capabilities
 - Bent Pipe vs. On board Processing
- Coverage and Usage Type
 - Coverage: global, regional, national → footprint
 - Usage: broadcast, two-way, mobile, etc.
- Not standards based as in cellular

U.S. Satellite Frequency Bands



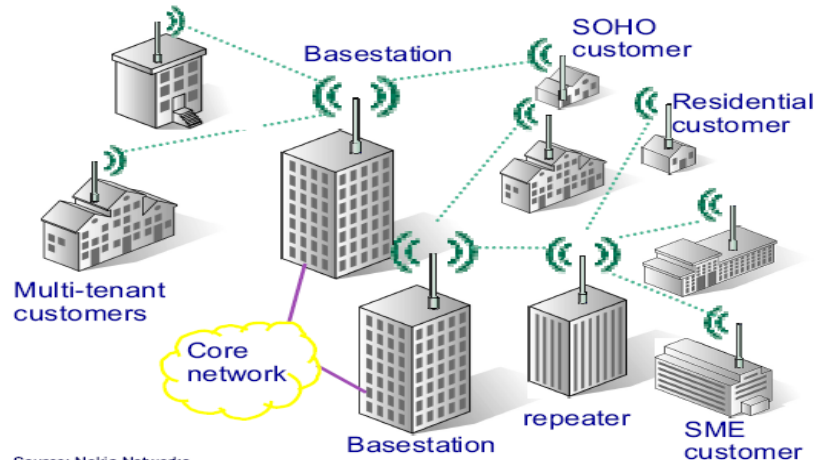
Licensed Spectrum - only

Band	Frequency Range	Total Bandwidth	General Application
L	1 to 2 GHz	1 GHz	Mobile satellite service (MSS)
S	2 to 4 GHz	2 GHz	MSS, NASA, deep space research
C	4 to 8 GHz	4 GHz	Fixed satellite service (FSS)
X	8 to 12.5 GHz	4.5 GHz	FSS military, terrestrial earth exploration, and meteorological satellites
Ku	12.5 to 18 GHz	5.5 GHz	FSS, broadcast satellite service (BSS)
K	18 to 26.5 GHz	8.5 GHz	BSS, FSS
Ka	26.5 to 40 GHz	13.5 GHz	FSS

Wireless MANs



- Wireless Metropolitan Area Networks (WMANs) : provide wireless connectivity across a geographical area the size of a city



Telcom 2720

35

Wireless MANs



- Wireless Metropolitan Area Network (WMAN)
 - Wireless alternative to DSL/cable modem/FTH services for last mile broadband access.
 - Point to Multipoint (PMP) protocol
 - Scope expanded to include mobility and higher data rates
 - IEEE 802.16 standard
 - Worldwide Interoperability for Wireless Microwave Access (WiMAX)
- Both licensed and unlicensed spectrum deployment
- Advantages: cost, flexibility, mobility



Telcom 2720

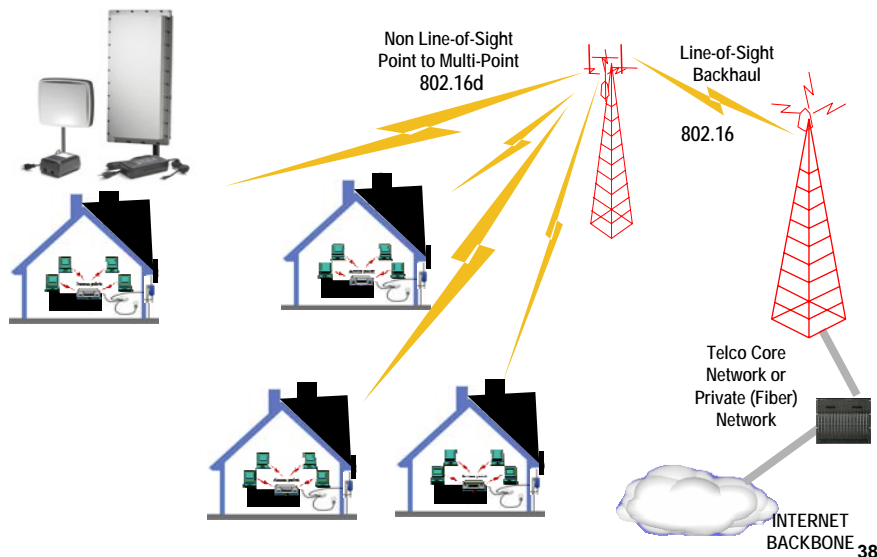
IEEE 802.16 /WiMAX Standard



- Characteristics of 802.16
 - Point to Multipoint (PMP) and Mesh protocol
 - NLOS wireless broadband services including bandwidth on demand
 - QoS support
 - Security
 - Scope expanded to include mobility and higher data rates
- Focus on both licensed and unlicensed spectrum deployment – supports multiple service providers/licenses in same area
- TDD and FDD duplexing support with flexible channel sizes
- 802.16 Terminology
 - Base Station (BS) is WiMAX cell site/access point
 - Subscriber Station (SS) is customer premise equipment and terminates the wireless link to the user location
 - Mobile Station (MS) is a standalone consumer device equipped with a WiMAX radio

Telcom 2720

WiMAX Architecture



Telcom 2720

WiMax Applications



- According to WiMax Forum it supports 5 classes of applications:
 1. Multi-player Interactive Gaming.
 2. VOIP and Video Conference
 3. Streaming Media
 4. Web Browsing and Instant Messaging
 5. Media Content Downloads
- Basically the Triple Play



Telcom 2720

39



Wireless LANs



- **Wireless Local Area Networks**

- Support communication to mobile **data** users via wireless channel
- Types of WLAN
 1. Infrastructure based (most popular)
 - Connect users to a wired infrastructure network
 - Wireless access network like cellular phone system
 - IEEE 802.11, a, b, g, n
 2. Ad-Hoc based networks
 - Provide peer to peer communication – mobiles communicate between each other directly
 - Rapid Deployment (conference room)
 - IEEE 802.11, a, b, g, n, Proprietary
 3. Point – to –Point (cable replacement!)



Telcom 2720

40

WLAN components



Wireless Fidelity standards for Interoperability
Components: access points, antennas, mobile stations

- 300 manufacturers
- www.wirelessethernet.org



Telcom 2720

41

IEEE 802.11 Terminology



- Access Point (AP)
 - Provides access to distribution services via the wireless medium
- Basic Service Area (BSA)
 - The coverage area of one access point
- Basic Service Set (BSS)
 - A set of mobile stations controlled by one access point
- Distribution system
 - The fixed (wired) infrastructure used to connect a set of BSS to create an **extended service set (ESS)**
- Portal(s)
 - The logical point(s) at which non-802.11 packets enter an ESS

Telcom 2720

42

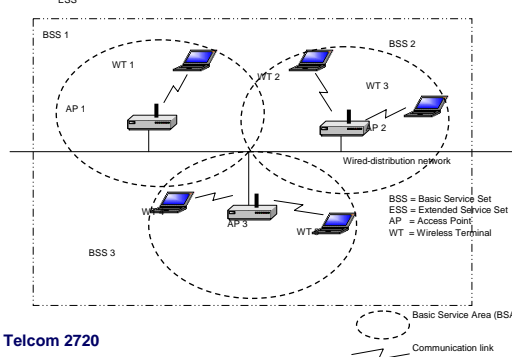
WLAN Topologies



ad-hoc based architecture

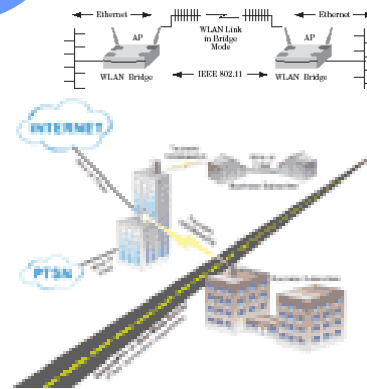


Infrastructure based architecture



Telcom 2720

Point-to-point



43

Wireless Personal Area Network



- Origins in the BodyLAN project initiated by BBN in the early 1990s
- Networking “personal” devices – sensors, cameras, handheld computers, audio devices, etc. with a range of around 5 feet around a soldier
- Today: Networking digital cameras to cell phones to PDAs to laptops to printers to etc.,
- Most popular application – hands free headset to cellphone
- IEEE 802.15 standard (Bluetooth)
 - Use band available globally for unlicensed users
 - Low powered – medium data rate ~100s kbps
 - Subgroups doing higher data rates and sensors (Zigbee)



Telcom 2720

44

Applications of WPANs

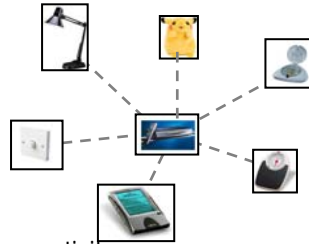


Cable Replacement

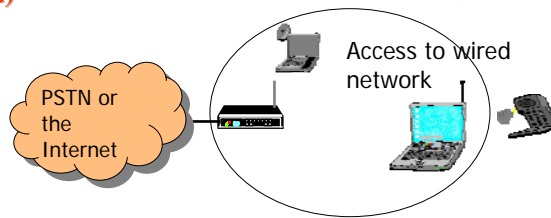


(a)

Ad hoc connectivity



(b)

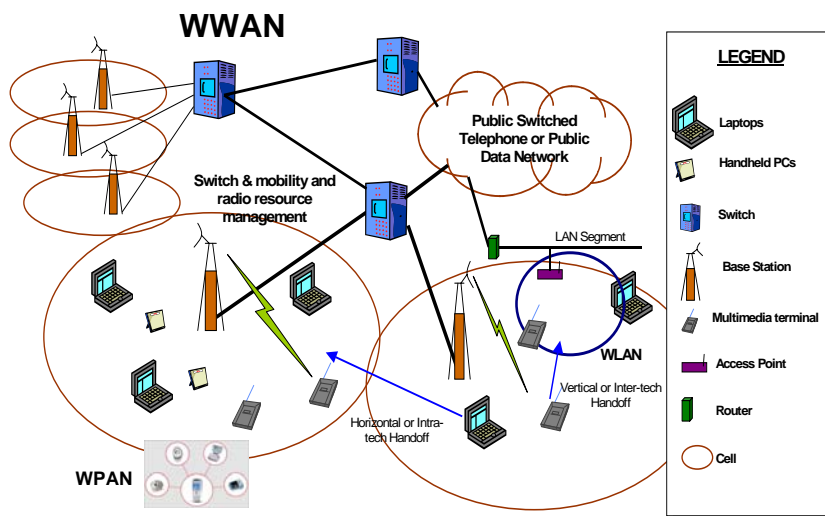


(c)

Telcom 2720

45

Example Network Architecture



Telcom 2720

46

Evolving Applications



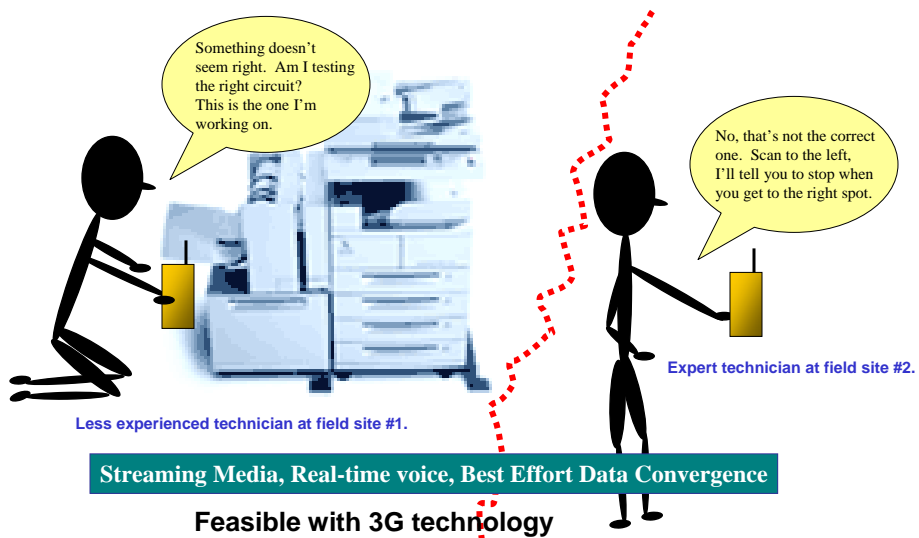
- Focus on data based services and value added applications
 - Mobile Internet Access
 - Mobile Intranet/Extranet Access
 - Personalized Infotainment
 - Video, audio, games, etc.
 - Multimedia Message Service (MM)
 - Location Based Services (LBS)
 - Rich Voice
- Theme
 - Multi-mode (multi-media) service
 - Community and identity



Telcom 2720

47

Example: Expert on Call



Telcom 2720

48

Sample Multimodal Applications



- Travel information
 - Make request via voice
 - Receive response in text
- Directions
 - Make request via voice
 - Receive initial response in text
 - Get updates while traveling via voice or SMS or map
- One-to-many messaging
 - Record message via voice or text
 - Deliver message via voice, SMS, or email
- Location Based Services
 - List of coffee houses in neighborhood,
 - List of friends in neighborhood
 - Directions to nearest X



Telcom 2720



Example Application



I am going to teach my phone my habits.

Looks cool!

Marie buys a new phone. She is showing it to her friend Susie.

After one week...

- Usually silent mode at location 3
- Always Meeting mode at location 4
- Diverting calls to answering machine at position 2
- Mobile phone ID#3144354 present usually at position 1*
- Travel time between 1 and 4 average 32min

The device has learnt where Marie likes to visit and what she does.

Marie gives names to positions.

Your phone is beeping

Look, it remembers!

Marie leaves to work, surprised that her phone helped her not to be late.

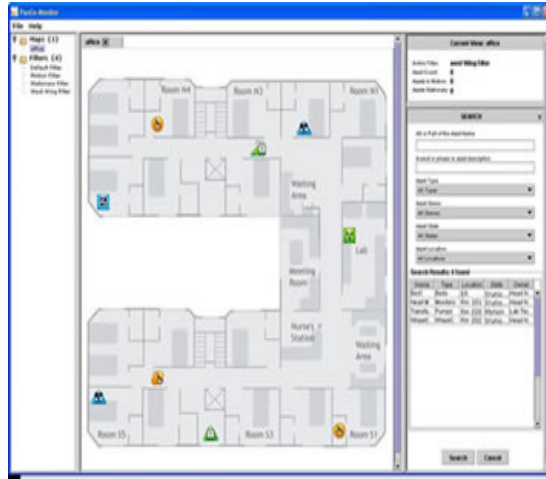
Telcom 2720

50

Asset Location



- Deploy WLAN in hospital
- Equipment given LAN ID tags
- Query to find.



Telcom 2720

51

Enablers



- Wireless network development
 - Increased bandwidth/data rate
 - Falling costs
 - Always on capability
 - WLAN – hotspots
- Mobile Devices
 - Fast development
 - More connectivity, computing power and autonomy, but lower size, weight and cost
 - More functionality – camera, mms, radio, gps, compass
- Software Infrastructure
 - wap, xml, VXML, J2ME, .NET CF, Device emulators, etc.
 - Smart Clients
 - mobile databases, synchronization technology
- Standardization
 - Software, protocols and hardware (e.g., Bluetooth). etc..

Telcom 2720

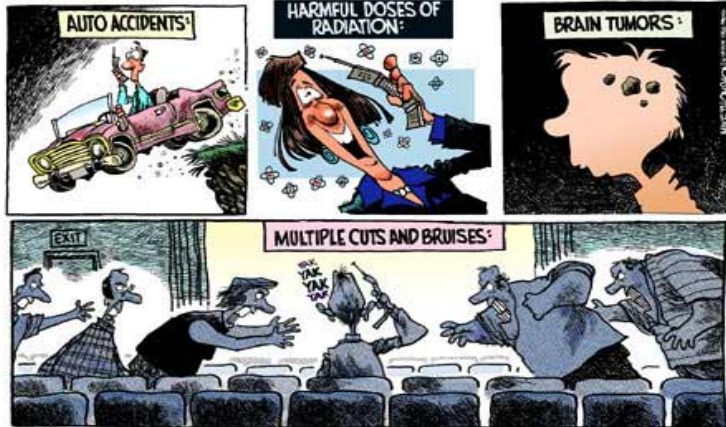
52



Safety of Mobile Communication Systems



Health Risks Associated with Cell Phone Usage:



Telcom 2720

53



Safety of Mobile Communication Systems



- **Concern about safety of mobile devices: rumoured and speculated danger**
 - Gas station explosions
 - Airplane crashes
 - Motor vehicle accidents
 - Brain cancer/tumours, fatigue
 - **Hard evidence to support these claims????**
- **Health effects of mobile communication systems**
 1. **Indirect:** contributing factor
 2. **Direct:** causal link



Telcom 2720

54



Indirect Health Effects



- **Gas Station Explosions**
 - No evidence other than distraction factor
- **Air Plane Crashes**
 - Some interference with avionics (old small planes)
 - Primarily asked to turn off phones for benefit of service provider – call serviced by multiple cells!
- **Motor Vehicle Accidents while on phone**
 - Several studies show **increased risk** of accidents
 - Appears to be a strong link



Telcom 2720

55



Indirect Health Effects



- **Motor Vehicle Accidents while on phone**
 - CTIA program to promote hands free calling or stopping to call
 - Many governments have regulations;
 - calling while driving illegal in some nations and states in U.S.
 - insurance companies considering special rates



Telcom 2720

56



Direct Health Effects



- **General Facts:**

- Mobile communication devices - **low** levels of radio frequency (RF) energy (max 5 W)
- RF band produces non-ionizing radiation
- Higher the frequency the greater the body penetration
 - Satellite band > WiMAX, WLAN band > PCS band > cellular band
- Higher the power level the greater the body penetration
 - Satellite phones > Analog phones > digital phones > WLAN's
- Handhelds riskier than vehicle mounted and base stations
- Duration of exposure to radiation matters
 - Longer > short



Telcom 2720

57



Health Effects of RF Radiation



- **Thermal Effects by holding device close to body**

- Heating due to RF radiation (like microwave oven)
- RF Energy amount depends on
 - Mobile device technology and frequency
 - Orientation of device and/or antenna
- Specific absorption rate **SAR** is metric to quantify energy
- Real SAR Measurements difficult
 - **FCC SAR limit 1.6 W/g average – Europe 1.6 W/10g**
 - Measured in human head model with jell like substance
 - Determine maximum SAR produced by device in head at fixed average power level
- Many medical studies on heating effect in last 3-5 years



Telcom 2720

58



Typical RF Radiation Pattern

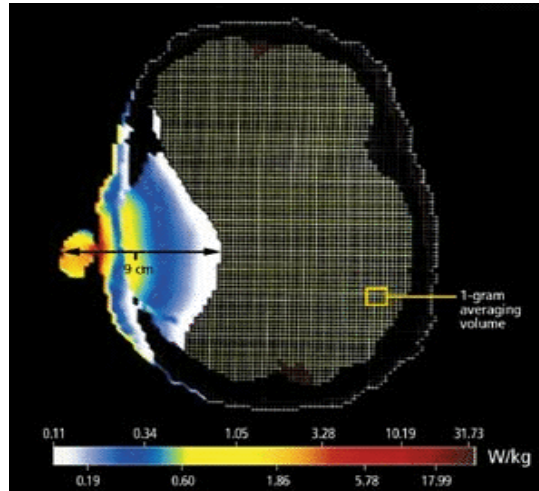


- SAR data posted on web. In U.S.A. by mobile phone FCC ID at www.fcc.gov/wtb

- SAR data required on mobile phone box in U.S.A.

- SAR Data provided by manufacturer with FCC check of procedure no independent verification.

- Typically report at average power level – not max power level



energy distribution in a human head from a cellular handset radiating 600 mW at 835 MHz. 59

Telcom 2720



Typical RF Medical Study Results



1. Brain cancer in rats after RF radiation exposure

Researchers, dates ^a	Exposure to RF radiation			No. of rats		Cancer	
	Frequency, MHz	SAR, W/kg	Duration, months	RF exposed	Unexposed	Tumor generation	
Brain tumor generation							
C.K. Chou et al., 1992	2450 PM	0.15–0.4	25	100	100	None	
J.C. Toler et al., 1997	435 PM	0.32	21	200	200	No significant difference between groups	
M.R. Frei et al., 1998	2450 FM	0.3	18	100	100	None	
M.R. Frei et al., 1998	2450 FM	1.0					
Brain tumor generation PLUS promotion of chemically induced tumors							
Researchers, dates ^a	Frequency	SAR	Duration	RF exposed ^b	Unexposed ^b	Tumor generation	Tumor promotion
W.R. Adey et al., 1999	837 PM	0.3–2.3	25	60 ^b	60	Insignificant decrease in RF-exposed rats	None
W.R. Adey et al., 2000	837 FM	0.3–2.3	26	90	90	No sig diff.	
B.C. Zook et al., 1999	860 FM	1	22	60	60	No sig diff.	
B.C. Zook et al., 1999	860 PM						

Telcom 2720

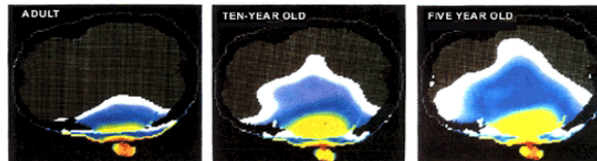
60



Mobile Devices Health Effects



- Studies thus far show *little health risk*
 - Long term effects *unknown*
 - Non-toxicological effects need study
 - Developmental effects *unknown* (nerve damage in kids?)
 - Effectiveness of shields very questionable
 - Effects of devices in different positions and different frequencies unknown (WLAN cards, hands free calling, WiMAX, etc.)
- Health Organizations: WHO, AMA, IGEMP (U.K.)
 - Recommend *precautionary* approach
 - More longer term studies
 - Limit exposure of children



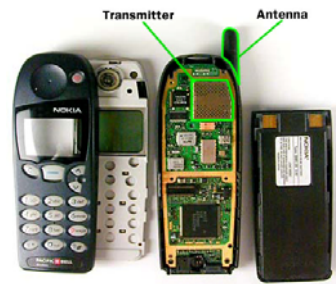
Telcom 2720

61

Summary



- Overview of Wireless Networks
 - WWANs (cellular, satellite)
 - WMANs (802.16 - wiMAX)
 - WLANs (802.11)
 - WPANs (802.15)
- Mobile Applications
- Health issues



Telcom 2720

62