Mobilnetze, dienstintegrierte Netze und Echtzeitkommunikation (MdNE)

engl.: Mobile Networks, Service-integrated Networks and Real-time Communications

Wahlpflichtmodul im Master-Studiengang

SoSe 2015

Prof. Dr. rer. nat. Bernd E. Wolfinger

– Telekommunikation und Rechnernetze –

Trends in Computer Science (CS) Research
or: How relevant is the topic „Computer Networking“ ?

cf.: [HSZ13] A. Hoonlor, B.K. Szymanski, M.J. Zaki: Trends in Computer Science Research, C. ACM, Vol. 56, No. 10,

Research Activities Related to CS Topics – world-wide (according to ACM & IEEE)

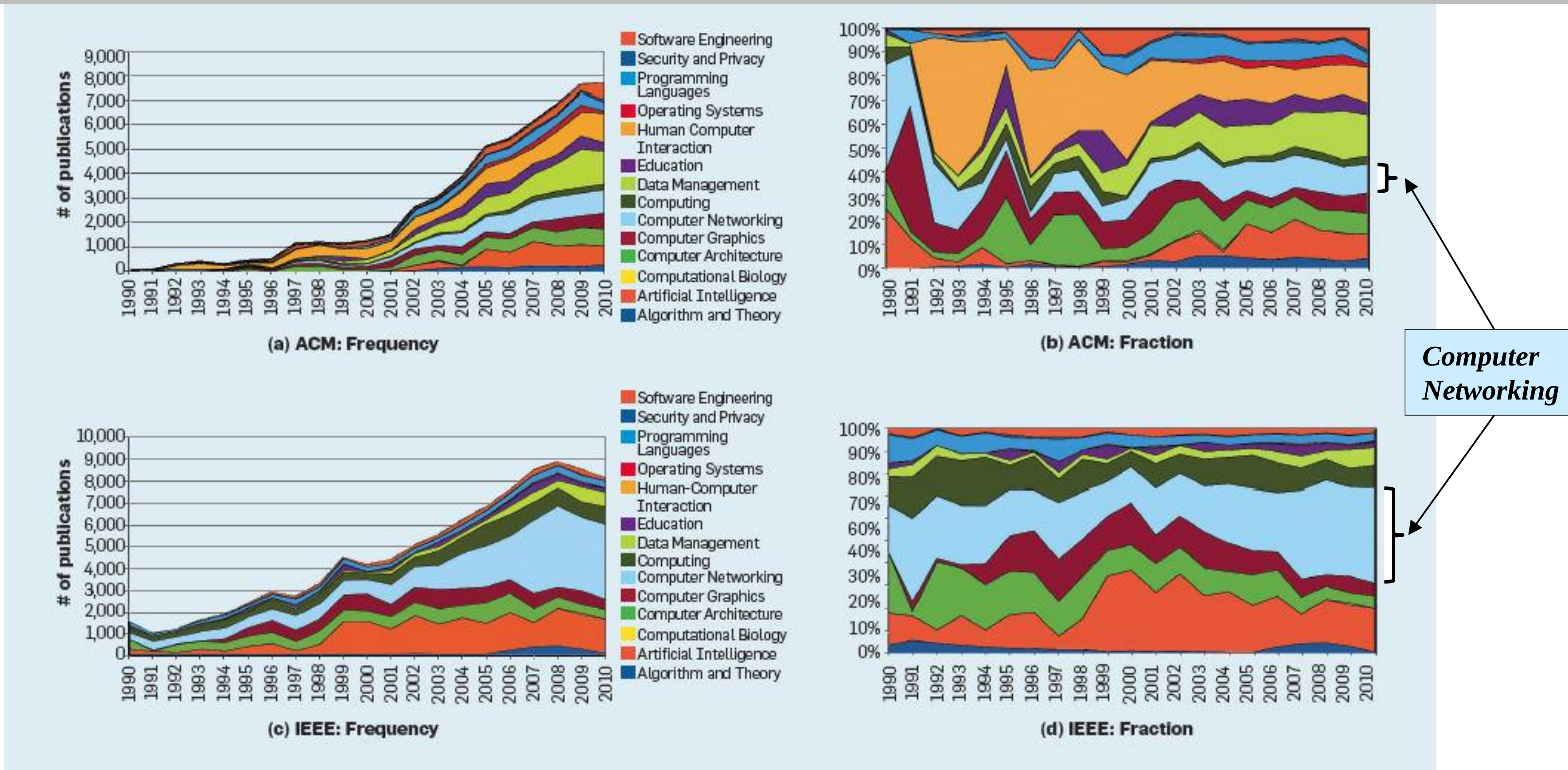

Figure 4. Landscape of *CS research fields, based on conferences 1990–2010*, for the ACM and IEEE datasets, including raw numbers (frequencies) and percentage of publications for each keyword each year. (Abb. aus: [HSZ13], s.o.)

Aus: ***Computer Zeitung***, *Nr. 12*, ***16. März 2009***

VDI befragt Mitglieder über die IT-Wachstumsbereiche bis 2015

Multimedia und mobiles Internet setzen wichtige Zukunftsimpulse

Die Wachstumsmärkte im IT-Bereich und Zukunftsprodukte hat der Ingenieursverein VDI bei 500 Mitgliedern abgefragt. Die Informatiker und Ingenieure haben sich auch zu den Konjunkturmaßnahmen geäußert.

Jeweils knapp über 40 Prozent der Befragten nennen als stärkste Wachstumsmärkte bis 2015 Multimedia-Anwendungen sowie mobiles Internet und Fernsehen. „Ebenso werden integrierte Systeme eine größere Rolle spielen“, erklärt Dieter Westerkamp, stellvertretender VDI-Leiter Technik und Wissenschaft. „Hier könnten Innovationen wie Brems- oder Spurhalteassistenten die Autoindustrie in Schwung bringen.“ 2008 seien in der Autoindustrie Embedded Systems für eine Milliarde Euro verbaut worden.

28 Prozent der Informatiker geht davon aus, dass Handel und Dienstleistungen per Internet zulegen werden. Gut ein Viertel nennt als weitere Wachstumsmärkte das Internet der Dinge und die Wissensvernetzung, 16 Prozent führen noch die virtuelle Produkt-Prozessentwicklung mit der digitalen Fabrik an.

„Nach Ansicht der Befragten werden die Verbraucher vor allem Navigationsgeräte kaufen und ortsbezogene Informationsdienste in Anspruch nehmen“, so Westerkamp. Jeweils knapp 65 Prozent sieht als Verkaufsschlager bis 2015 Fernsehen über das Internet und Video-on-Demand, Multimediageräte und die IP-Telefonie.

„Zwei Drittel glauben, dass die geplanten Maßnahmen der Bundesregierung zur Krisenbewältigung Wirkung zeigen werden“, berichtet der VDI-Manager. Als Konjunkturkurbeln sehen über der Hälfte vor allem den Ausbau des Breitbandnetzes sowie die Investitionen in Bildungseinrichtungen und die bessere Ausstattung von Schulen mit PCs und Internetzugängen an.

Als wirksam gelten auch der Aufbau intelligenter Verkehrsinfrastrukturen (46 Prozent) und die Zuschüsse für Investitionen in umwelt- und ressourcenschonende IKT-Systeme (31 Prozent). Westerkamp: „Hier würde nicht nur die Wirtschaft, sondern auch die Umwelt profitieren.“

Informatiker sind laut VDI trotz Krise Mangelware. „Mit 176 000 beschäftigten Informatikern wurde 2008 ein Höchststand erreicht – selbst im Boomjahr 2000 waren es noch 21 Prozent weniger“, so Westerkamp. 18 000 Informatiker werden gesucht, 6700 seien arbeitslos, „ein Rückgang um acht Prozent“. rr

Mobiles Internet wird Alltag

Datum: 28.02.2013   URL: http://www.cio.de/2908147
aus: CIO Magazin / CIO Exklusiv Newsletter

Vier Tage lang hat der Mobile World Congress im sonnigen Barcelona die aktuellen Trends der Mobilfunkbranche beleuchtet. Ein Ergebnis: Smartphones sind nur der Anfang. Das mobile Internet wird Freizeit, Arbeitsleben und Gesellschaft grundlegend verändern. Barcelona (dpa) - Das mobile Internet wird so wichtig wie Wasser und Strom. In diesem beweglichen digitalen Raum geht es künftig nicht nur darum, unterwegs die E-Mail zu lesen oder ein Foto auf Facebook hochzuladen. Die Fachmesse Mobile World Congress hat in dieser Woche gezeigt, wie die Vernetzung über Mobilfunk alle Lebensbereiche erfasst.

Im Internet der Dinge fangen die Gegenstände zu denken an, wie auf einem Stand des spanischen Netzbetreibers Telefónica zu lesen war. Bis 2020 werden 50 Milliarden Geräte aller Art miteinander vernetzt sein, schätzt der Chef des schwedischen Netzausrüsters Ericsson, Hans Vestberg. Sie werden im Autoverkehr, im Krankenhaus oder in der Warenlogistik von Unternehmen automatisch Daten austauschen, ihre Software wird selbstständige Entscheidungen treffen. Die erforderliche Debatte darüber hat kaum begonnen. Wer sich daran beteiligen will, sollte aufhorchen, wenn das Schlagwort M2M fällt: Kommunikation von Maschine zu Maschine.

...

Wie geht es weiter mit dem mobilen Internet? Eine Gesprächsrunde zur fernen Zukunft in zehn Jahren malte sich die jetzt schon erkennbaren Trends weiter aus: Die Geräte werden so dünn wie Papier, Software umgibt uns in allen möglichen Gegenständen, und das Web ist so intelligent, dass es uns stets die gerade wichtigen Informationen bereitstellt - zur richtigen Zeit und am richtigen Ort.

Die Branche zeigt sich optimistisch, dass der Mobilfunk auch die entferntesten Regionen der Welt erschließen werde. "Wir müssen 100 Prozent der Weltbevölkerung ans Netz bringen", fordert der Vorstandschef des größten indischen Mobilfunkbetreibers Bharti Airtel, Manoj Kohli. Noch ein Stück weiter blickt Carlos Domingo vom spanischen Netzanbieter Telefónica: "In zehn Jahren werden wir in der Lage sein, vom Mars aus über ein mobiles Netzwerk zu kommunizieren", verkündete er augenzwinkernd.

***Remark:** Some of the motivation given partially in German language → please excuse !!!*

THE BENEFITS OF MOBILE COMMUNICATIONS

Mobile telecommunications, which were regarded as a luxury only two decades ago, are now ubiquitous, and vitally important to individuals, to communities, to businesses, and to the wider economy. Local authorities have an important role to play in enabling access to mobile communications for their communities.

There are now more than 81 million mobile connections in the UK as a whole, and around 4.8 million customers now access mobile broadband via a laptop and dongle.[1)] Mobile is fast becoming the web access medium of choice, fuelled by the growth of smartphones, tablets, and laptop and dongle. The increasing use of mobile broadband services via dongles and smartphones resulted in a 67% increase in data transferred over the UK's mobile networks in 2010. At the end of 2010, over a quarter of adults (27 per cent) and almost half of teenagers (47 per cent) owned a smartphone and 28 per cent of people use their mobile phones for internet access.[2)] By 2015, 75% of all phones will be smart phones, and by 2014, 20% of computers will be tablets.[3)]

What is more important than these statistics, impressive though they may be, are the benefits mobile communications bring to individuals. Connecting to the Internet via a mobile device allows people to access a wide range of central and local government services; to do research for a school project or apply to university; to manage their bank account and pay bills; to apply for a job; or to buy groceries.

Most local authorities' services are now available online, and many councils have recognised the growth of smartphone use and introduced mobile phone applications to provide instant access to services, or to allow residents to report litter, dumped rubbish, pot holes and road repairs, or anti-social behaviour. The health services also benefit from good mobile connectivity. The advantages of being able to summon the emergency services using a mobile phone is obvious, but simply sending text messages to patients means fewer missed appointments, and saves the NHS both time and money.

The Internet is now also increasingly important in education. A fifth of teachers think it 'essential' for children to be able to surf the web to be able to do their homework properly, while 61% think it 'advisable'.[4)] Digital literacy and connectivity are to the present day what reading, writing and the provision of libraries were to the Nineteenth century.

Today, people are more likely to rely on a mobile phone than on a landline: around 15% of UK households rely on mobile as their only means of voice telephony, while only 6% have only a fixed line. People in socio-economic groups D & E are even more likely than the better-off to live in a mobile-only household, or to access the Internet using a mobile connection than they are to have just a landline or to access the web through a fixed connection: one in four DE households were mobile-only in Q1 2011.[5)]

Good mobile connectivity is also vital to the business sector. Its importance to 'new economy sectors', including those in the creative industries, is obvious, but it is also vital to more traditional sectors, such as manufacturing, tourism, and food and drink. The Internet allows firms to research markets, advertise their wares to potential customers, and to take orders. And while many people now shop online, others also use the internet to complement their more traditional shopping habits, to find the location of a particular store, or to check whether particular items are in stock.

Local authorities have an important role to play in enabling access to all these services for their communities. Mobile phones, dongles, and tablet computers cannot work without a network of base stations (masts), and so local planning authorities should actively support the expansion of the electronic communications networks, including telecommunications and high speed broadband.

[1), 5)] Ofcom, Communications Market Report 2011

[2)] ibid

[3)] Industry estimates -Spider Online 2011

[4)] TES survey summer 2010

Quelle: MOA, Russell Square House, 10-12 Russell Square, London WC1B 5EE, www.mobilemastinfo.com

Aus: ***http://www.malvernhills.gov.uk/cms/pdf/Benefits%20of%20Mobile%20Communications%20Factsheet.pdf***

CONTENT: *Part A* "**Wireless and Mobile Networks**" & *Part B* "**Media and Real-time Communications; Service-integrated Networks**"

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Part A “**Wireless and Mobile Networks**”

Ackowledgement to:
Jim Kurose & Keith Ross

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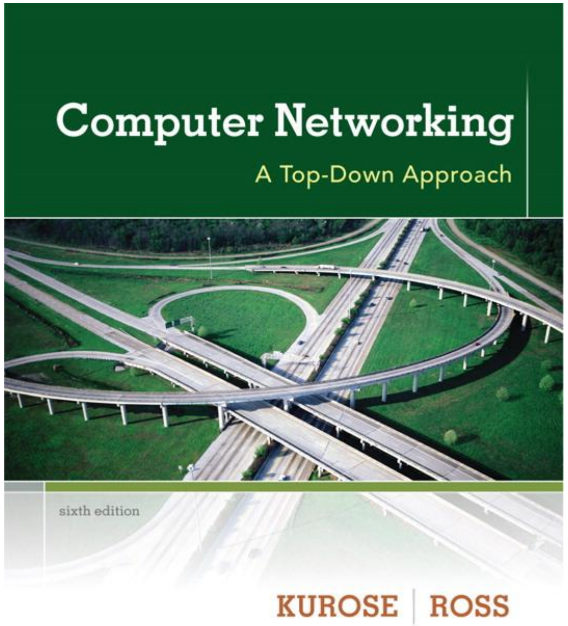


Computer Networking: A Top Down Approach
6th edition
Jim Kurose, Keith Ross
Addison-Wesley
March 2012

Zusatzkommentar B.E. Wolfinger:
Aus den obigen Ausführungen folgt natürlich, dass die PPT-Folien der MdNE-Vorlesung allesamt nur zum persönlichen Gebrauch der Studierenden bestimmt sind und sämtliche Copyright-Rechte (u.a. diejenigen von J. Kurose & K. Ross) uneingeschränkt zu respektieren sind !

Part **A**: Wireless and Mobile Networks

Background:

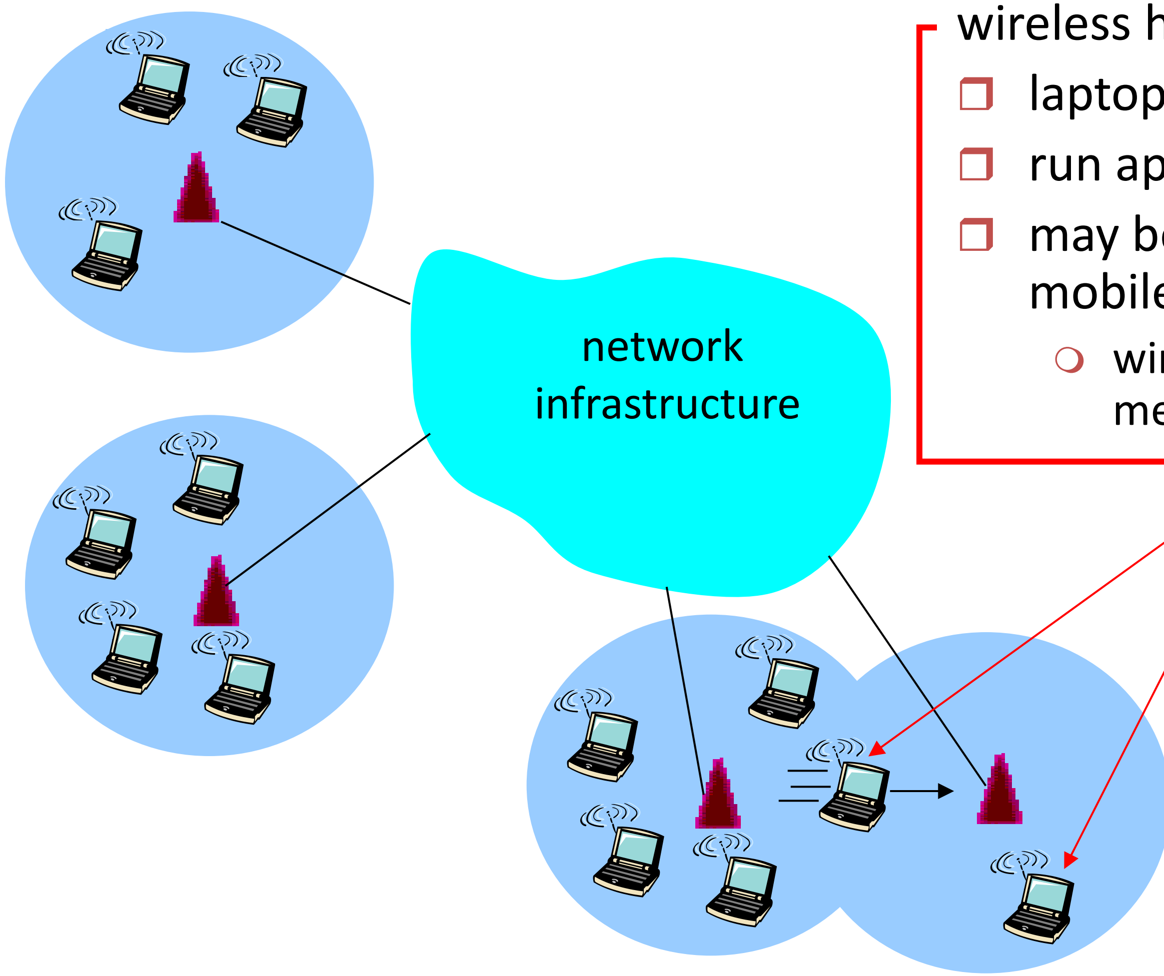
- # wireless (mobile) phone subscribers now exceeds # wired phone subscribers (5-to-1)!
- # wireless Internet-connected devices equals # wireline Internet-connected devices
  - laptops, Internet-enabled phones promise anytime untethered Internet access
- two important (but different) challenges
  - *wireless:* communication over wireless link
  - *mobility:* handling the mobile user who changes point of attachment to network

Part A "**Wireless and Mobile Networks**"

A1. Some Basics of Mobile Networks

A1.1 Introduction

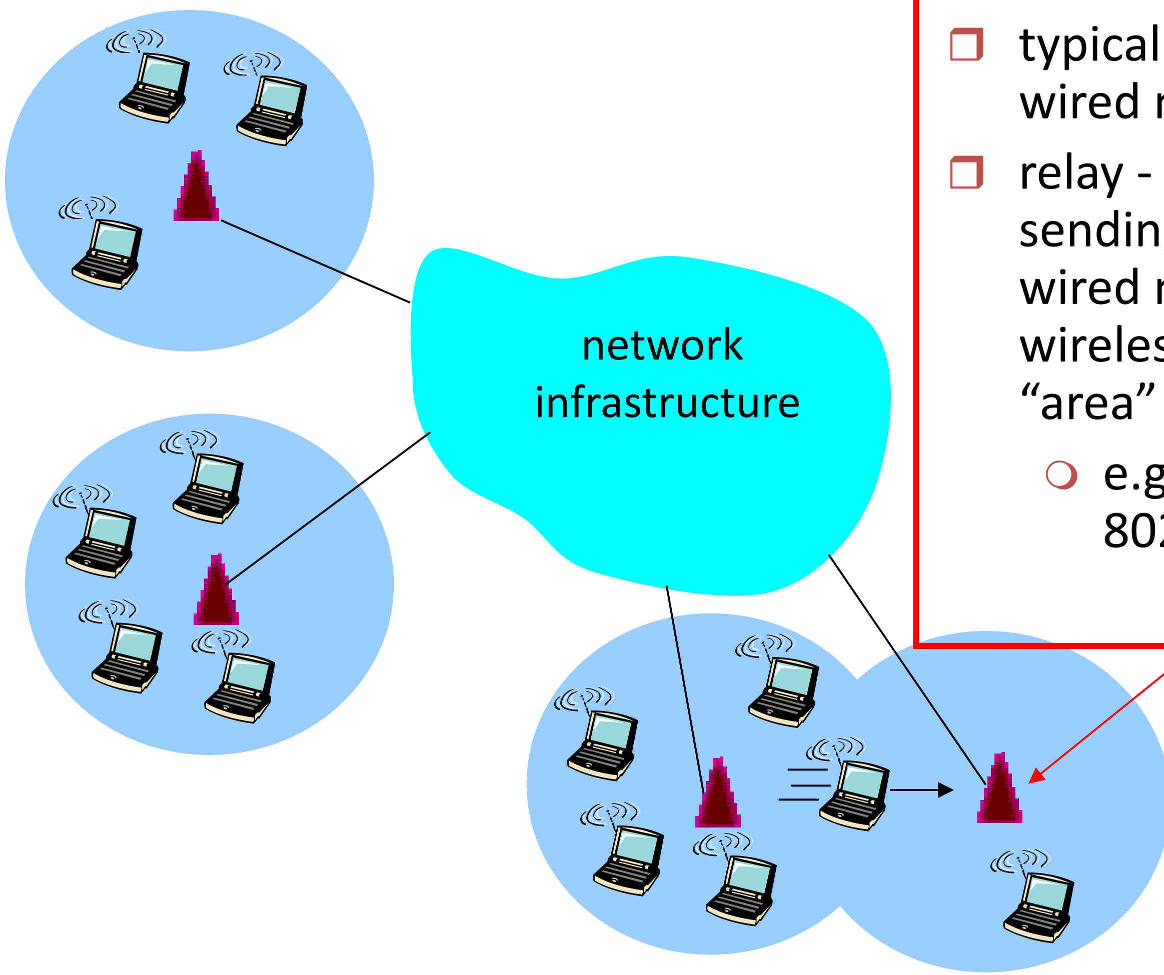
Elements of a wireless network



wireless hosts

- laptop, PDA, IP phone
- run applications
- may be stationary (non-mobile) or mobile
  - wireless does *not* always mean mobility

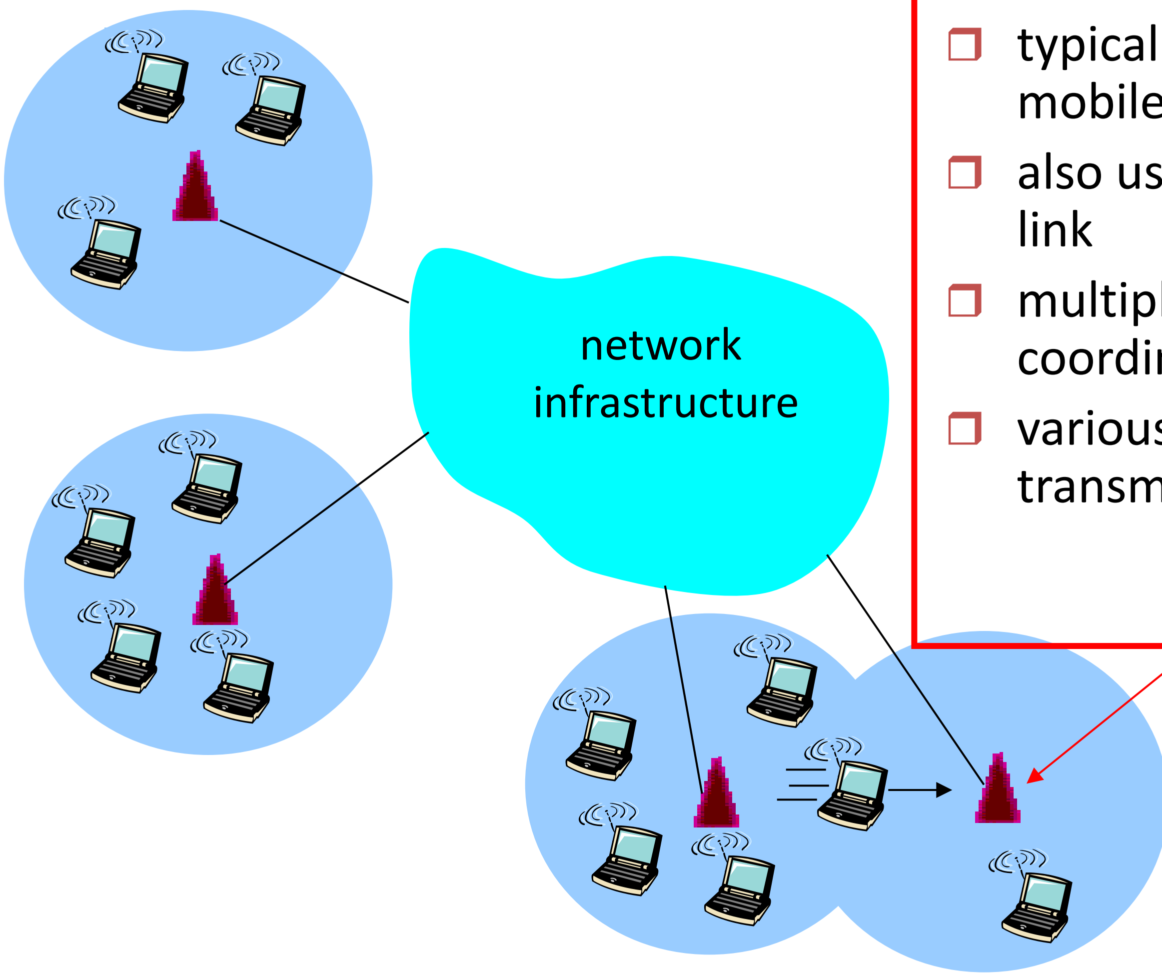
Elements of a wireless network



base station

- typically connected to wired network
- relay - responsible for sending packets between wired network and wireless host(s) in its "area"
  - e.g., cell towers, 802.11 access points

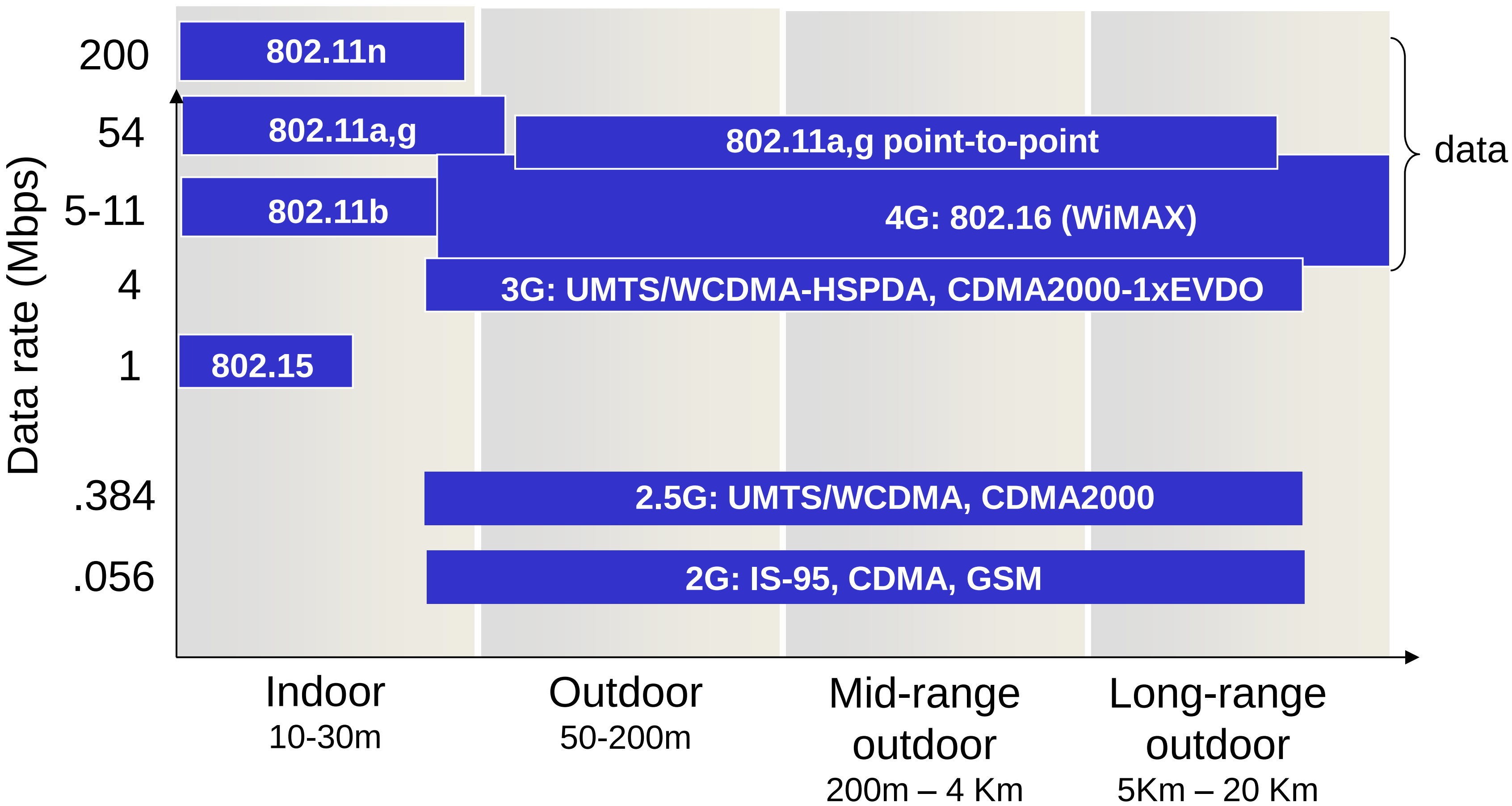
Elements of a wireless network



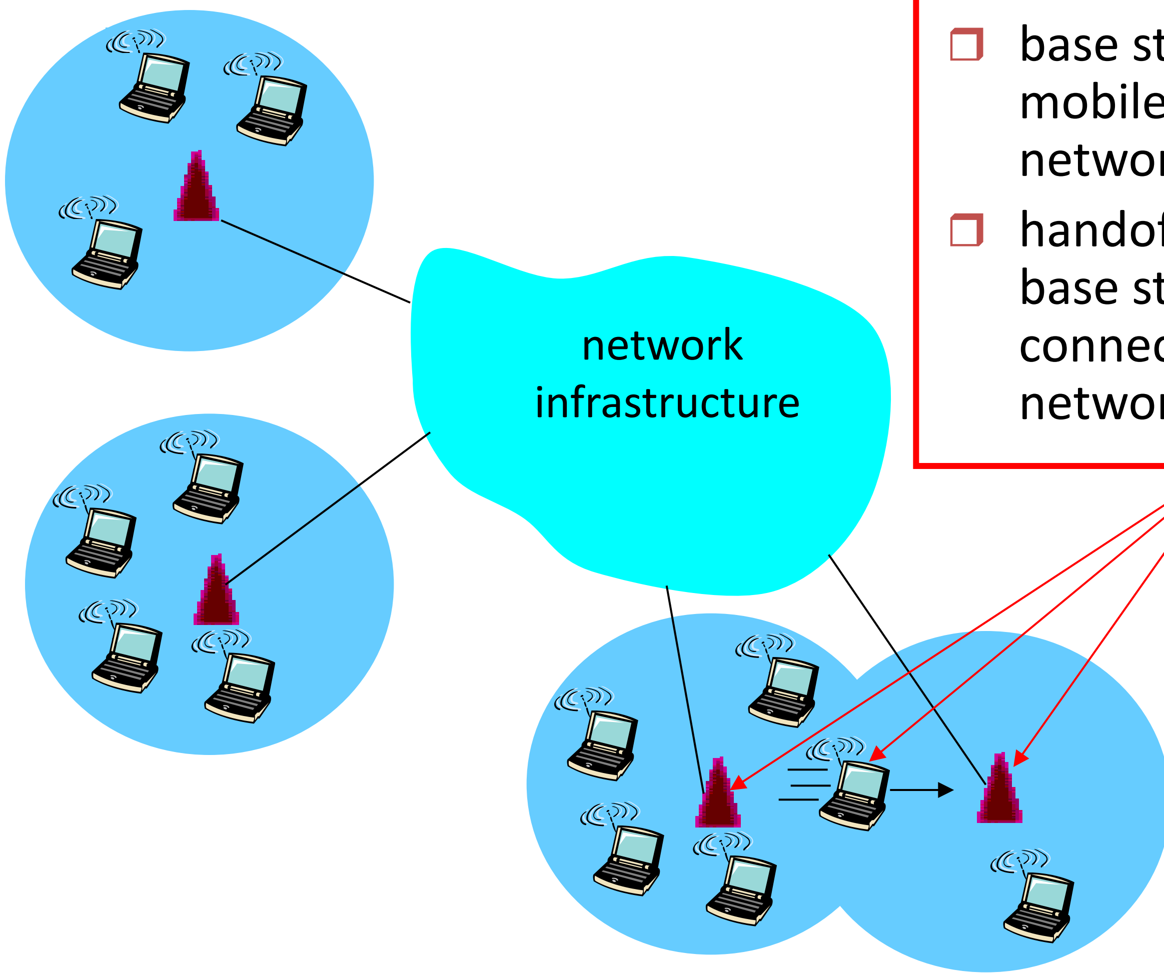
wireless link

- typically used to connect mobile(s) to base station
- also used as backbone link
- multiple access protocol coordinates link access
- various data rates, transmission distance

Characteristics of selected wireless link standards



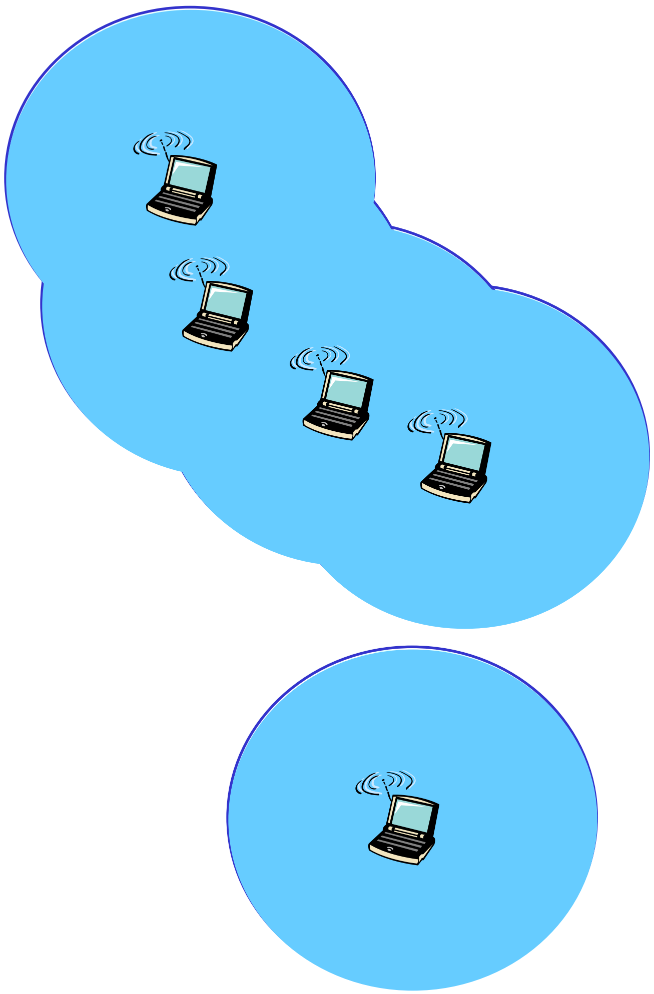
Elements of a wireless network



infrastructure mode

- base station connects mobiles into wired network
- handoff: mobile changes base station providing connection into wired network

Elements of a wireless network



ad hoc mode

- no base stations
- nodes can only transmit to other nodes within link coverage
- nodes organize themselves into a network: route among themselves

Wireless network taxonomy

	single hop	multiple hops
infrastructure (e.g., APs)	Host connects to base station (WiFi, WiMAX, cellular) which connects to larger Internet	Host may have to relay through several wireless nodes to connect to larger Internet: *mesh net*
no infrastructure	No base station, no connection to larger Internet (Bluetooth, ad hoc nets)	No base station, no connection to larger Internet. May have to relay to reach another given wireless node MANET (Multi-hop Ad Hoc Network), VANET (Vehicular Ad Hoc Network)

Classes of Mobility in Wireless Networks: Examples

- *No Mobility:*
  - Sensor Network with stationary sensor nodes (i.e. nodes placed at fixed locations)
  - WLAN replacing an Ethernet to interconnect stationary desktop computers, PCs, etc.
- *Low Mobility:* ~ 1 mile/h
  - Wireless Mesh Network with stationary or slowly moving network nodes (e.g. persons walking slowly)
  - Sensor Network with sensor nodes attached to slowly moving animals
- *High Mobility:* ~ 100 miles/h
  - Vehicular Ad-hoc Network (VANET) with mobile nodes in cars (e.g. driving on high-way)

$\rightarrow$ strong implication on complexity of routing protocols

A1.2 Wireless Links and Network Characteristics

Wireless Link Characteristics (1)

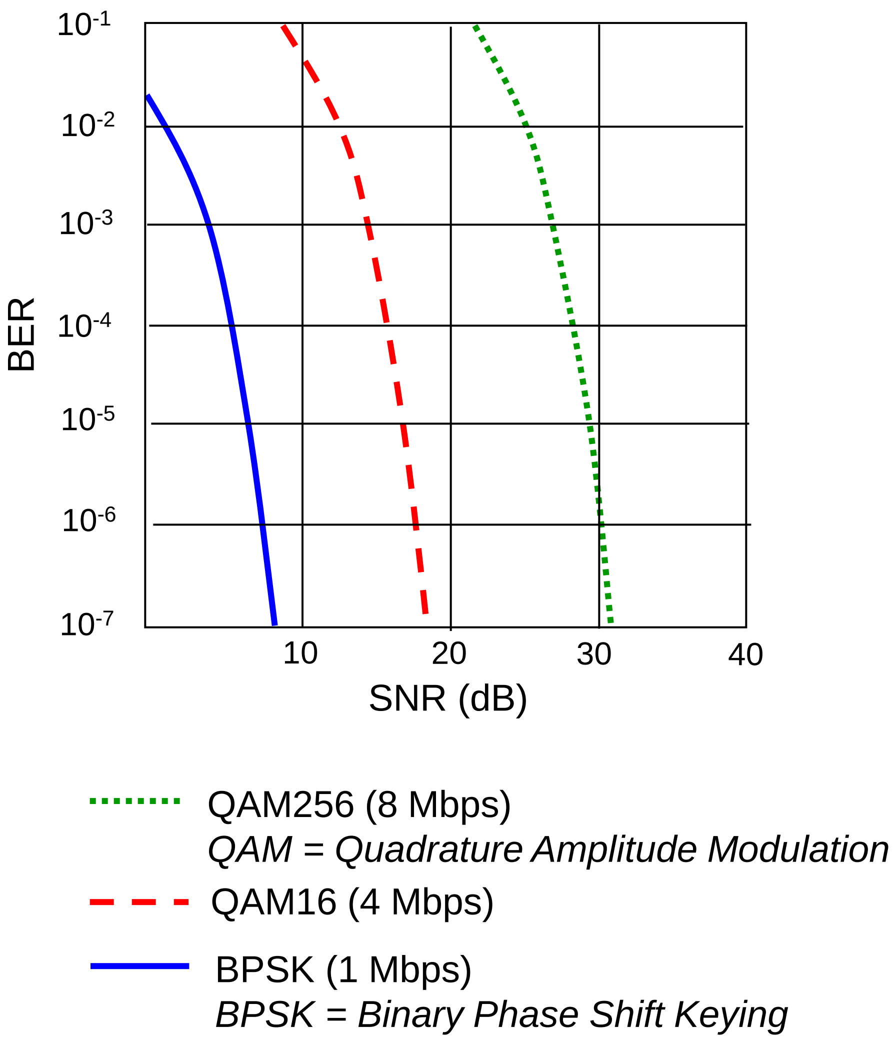
Important differences from wired link ….

- decreased signal strength: radio signal attenuates as it propagates through matter (path loss)
- interference from other sources: standardized wireless network frequencies (e.g., 2.4 GHz) shared by other devices (e.g., phone); devices (motors) interfere as well
- multipath propagation: radio signal reflects off objects ground, arriving at destination at slightly different times

…. make communication across (even a point to point) wireless link much more "difficult"

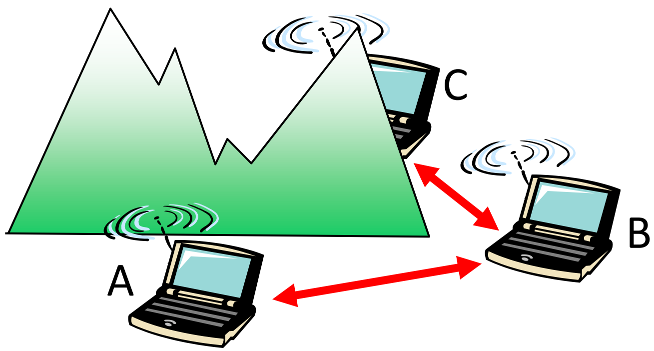
Wireless Link Characteristics (2)

- SNR: signal-to-noise ratio
  - larger SNR – easier to extract signal from noise (a "good thing")
- *SNR versus BER tradeoffs*
  - *given physical layer:* increase power → increase SNR → decrease BER (bit error rate)
  - *given SNR:* choose physical layer that meets BER requirement, giving highest throughput
    - SNR may change with mobility: dynamically adapt physical layer (modulation technique, rate)



Wireless network characteristics

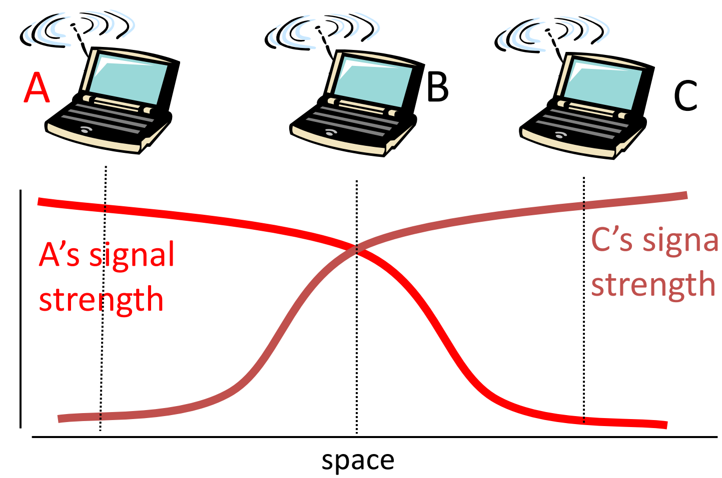
Multiple wireless senders and receivers create additional problems (beyond multiple access):



Hidden terminal problem

- B, A hear each other
- B, C hear each other
- A, C can not hear each other

means A, C unaware of their interference at B



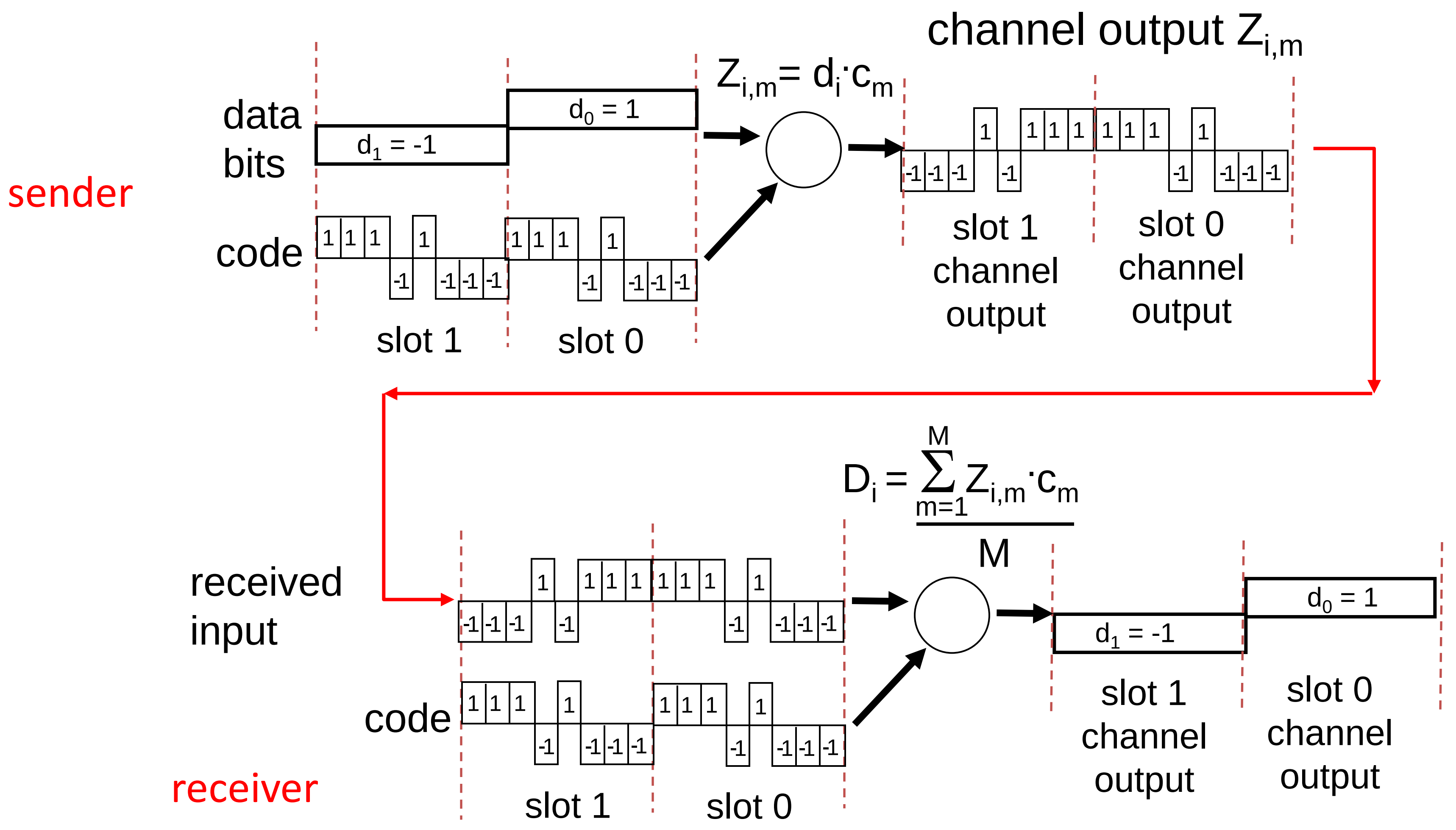
Signal attenuation:

- B, A hear each other
- B, C hear each other
- A, C can not hear each other interfering at B

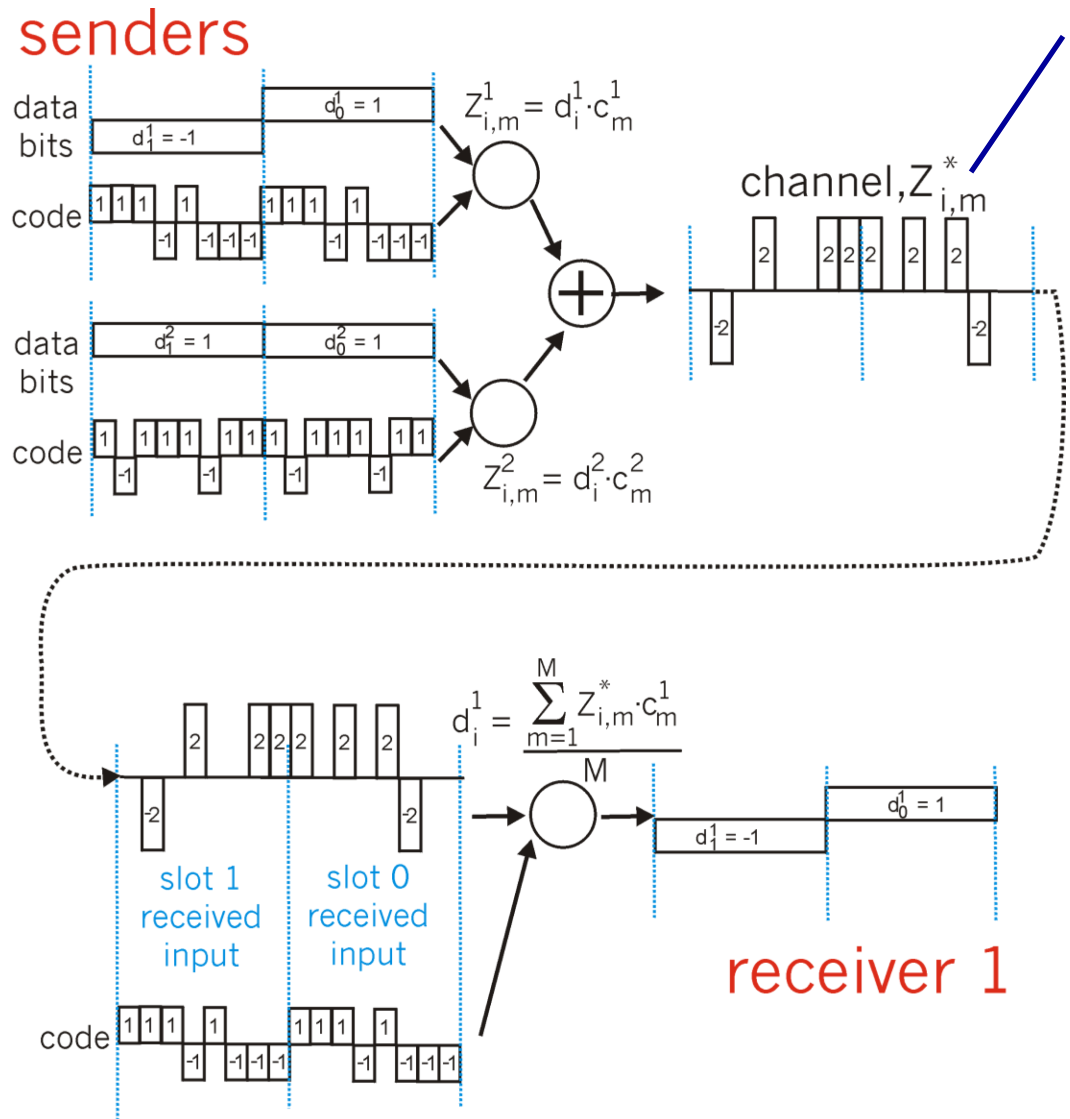
Code Division Multiple Access (CDMA)

- used in several wireless broadcast channels (cellular, satellite, etc) standards
- unique "code" assigned to each user; i.e., code set partitioning
- all users share same frequency, but each user has own "chipping" sequence (i.e., code) to encode data
- *encoded signal* = (original data) X (chipping sequence)
- *decoding:* inner-product of encoded signal and chipping sequence
- allows multiple users to "coexist" and transmit simultaneously with minimal interference (if codes are "orthogonal")

CDMA Encode/Decode



CDMA: two-sender interference



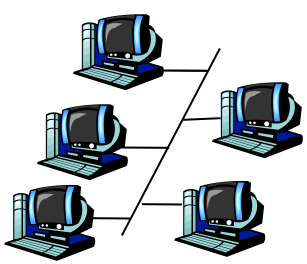
channel sums together transmissions by sender 1 and 2

using same code as sender 1, receiver recovers sender 1's original data from summed channel data!

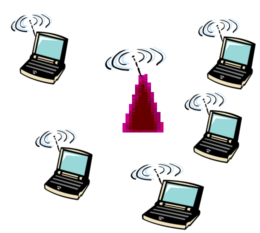
A1.3 Multiple Access Links and Protocols

Two types of “links”:

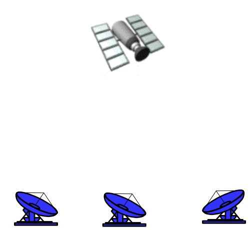
- point-to-point
  - PPP (Point-to-Point Protocol) for dial-up access
  - point-to-point link between Ethernet switch and host
- broadcast (shared wire or medium)
  - old-fashioned Ethernet
  - upstream HFC (hybrid fiber coax)
  - 802.11 wireless LAN



shared wire (e.g., cabled Ethernet)



shared RF (e.g., 802.11 WiFi)



shared RF (satellite)

humans at a cocktail party (shared air, acoustical)

Multiple Access Protocols

- single shared broadcast channel
- two or more simultaneous transmissions by nodes: interference
  - collision if node receives two or more signals at the same time

multiple access protocol

- distributed algorithm that determines how nodes share channel, i.e., determine when node can transmit
- communication about channel sharing must use channel itself!
  - no out-of-band channel for coordination

Ideal Multiple Access Protocol

given: broadcast channel of rate R bps (bps = bit per sec)

desiderata:

1. when one node wants to transmit, it can send at rate R.
2. when M nodes want to transmit, each can send at average rate R/M
3. fully decentralized:
   - no special node to coordinate transmissions
   - no synchronization of clocks, slots
4. simple

MAC Protocols: a taxonomy

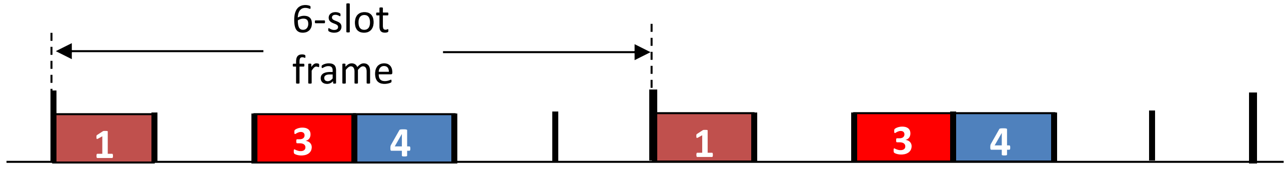
Three broad classes:

- **Channel Partitioning** [DKR ("Datenkommunikation und Rechnernetze") course / Classification by Luczak: ≈ **Reservierungs**-verfahren]
  - divide channel into smaller "pieces" (time slots, frequency, code)
  - allocate piece to node for exclusive use
- **Random Access** [Classification by Luczak: Verfahren mit **zufälligem Zugriff**]
  - channel not divided, allow collisions
  - "recover" from collisions
- **"Taking Turns"** [Classification by Luczak: ≈ **Aufforderungs**-verfahren]
  - nodes take turns, but nodes with more to send can take longer turns

Channel Partitioning MAC protocols: TDMA

TDMA: time division multiple access

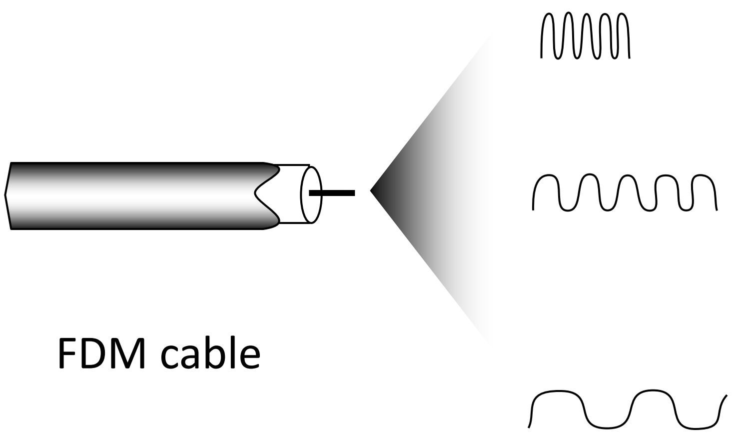
- access to channel in "rounds"
- each station gets fixed length slot (length = pkt trans time) in each round
- unused slots go idle
- example: 6-station LAN; slots 1,3,4 have pkt; slots 2,5,6 idle

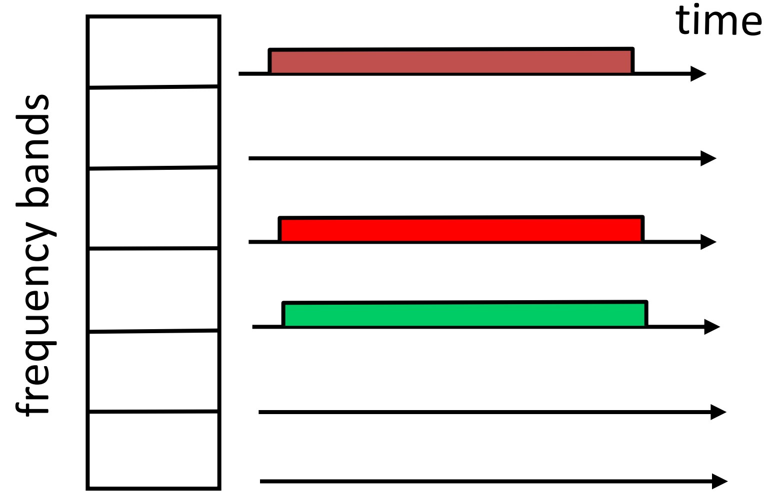


Channel Partitioning MAC protocols: FDMA

FDMA: frequency division multiple access

- channel spectrum divided into frequency bands
- each station assigned fixed frequency band
- unused transmission time in frequency bands go idle
- example: 6-station LAN; 1,3,4 have pkt; frequency bands 2,5,6 idle





Random Access Protocols

- When node has packet to send
  - transmit at full channel data rate R
  - no *a priori* coordination among nodes
- two or more transmitting nodes ➜ "collision",
- random access MAC protocol specifies:
  - how to detect collisions
  - how to recover from collisions (e.g., via delayed retransmissions)
- Examples of random access MAC protocols:
  - *slotted ALOHA*
  - *ALOHA*
  - *CSMA* (Carrier Sense Multiple Access), *CSMA/CD* (CD: Collision Detection), *CSMA/CA* (CA: Collision Avoidance)

Slotted ALOHA

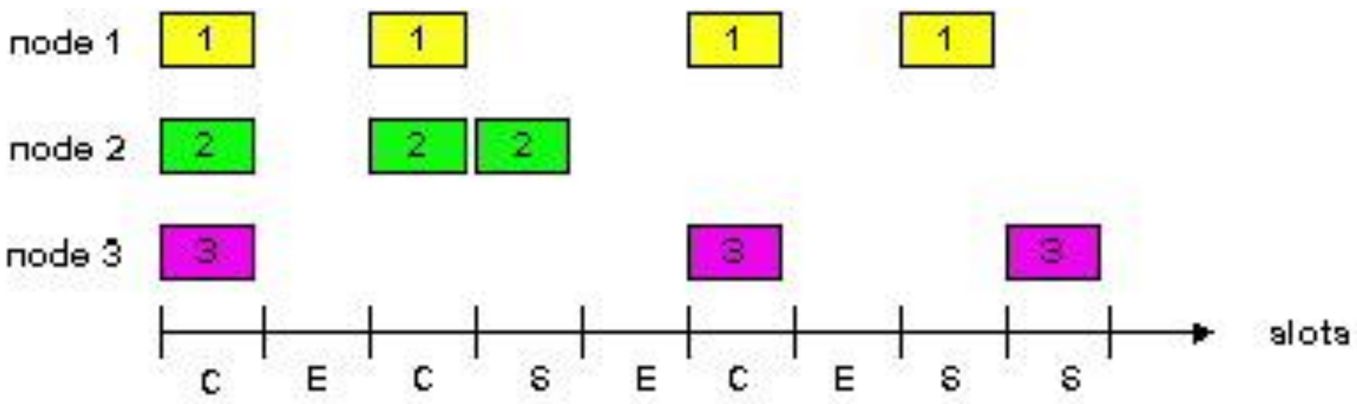
Assumptions:

- all frames same size
- time divided into equal size slots (time to transmit 1 frame)
- nodes start to transmit only slot beginning
- nodes are synchronized
- if 2 or more nodes transmit in slot, all nodes detect collision

Operation:

- when node obtains fresh frame, transmits in next slot
  - *if no collision:* node can send new frame in next slot
  - *if collision:* node retransmits frame in each subsequent slot with prob. p until success

Slotted ALOHA



C: collision; **E**: empty; **S**: success

Pros:

- single active node can continuously transmit at full rate of channel
- highly decentralized: only slots in nodes need to be in sync
- simple

Cons:

- collisions, wasting slots
- idle slots
- nodes may be able to detect collision in less than time to transmit packet
- clock synchronization

Slotted Aloha efficiency

Efficiency : long-run fraction of successful slots (many nodes, all with many frames to send)

- *suppose:* N nodes with many frames to send, each transmits in slot with probability *p*
- prob that given node has success in a slot = $p(1-p)^{N-1}$
- prob that *any* node has a success = $Np(1-p)^{N-1}$

- max efficiency: find p* that maximizes $Np(1-p)^{N-1}$
- for many nodes, take limit of $Np^*(1-p^*)^{N-1}$ as N goes to infinity, gives:

Max efficiency = 1/e = .37

At best: channel used for useful transmissions 37% of time!

!

Slotted Aloha efficiency
for favorable traffic assumptions

- Traffic favorable, e.g., if only a few – possibly only a single (!) – sender(s) OR “Request-Reply”-communication between a client and a server (with negligible delays in client and server but a lot of data to be transferred as requests and/or replies).

→ Probability of collisions may become negligible !

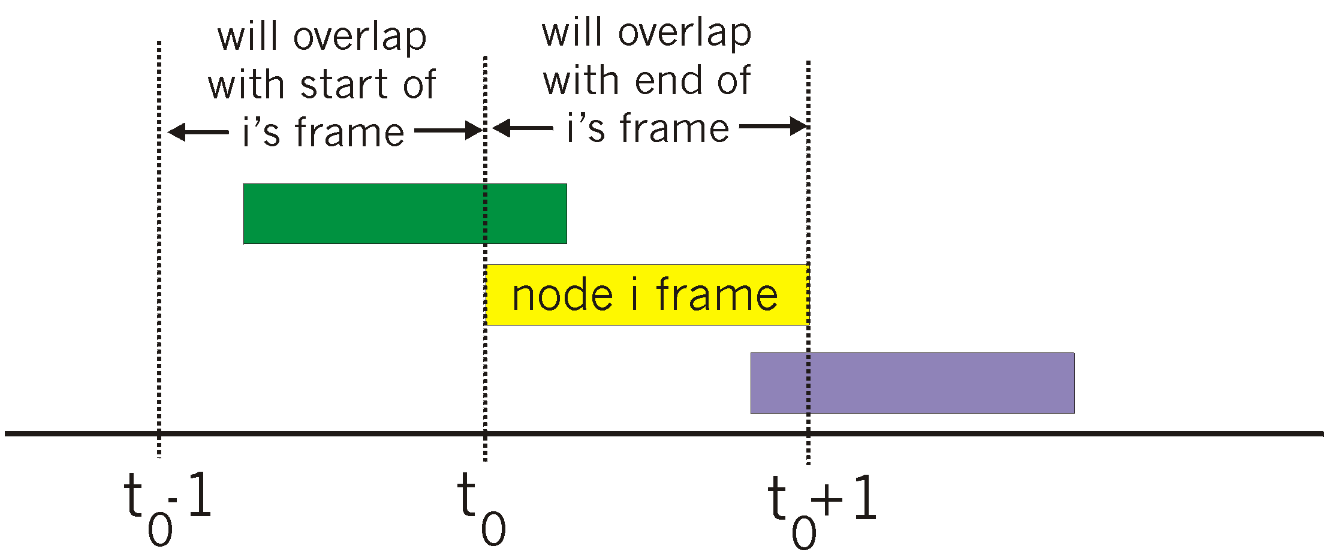
Now, at best: channel used for useful transmissions 100 % of time, i.e. maximum utilization tending towards 1.0 – and maximum throughput achievable tending towards the data rate of the channel !

… so, please be careful in taking into account the assumptions made in performance evaluation studies

!!!

Pure (unslotted) ALOHA

- unslotted Aloha: simpler, no synchronization
- when frame first arrives
  - transmit immediately
- collision probability increases:
  - frame sent at t_0 collides with other frames sent in $[t_0\text{-}1, t_0\text{+}1]$



Pure Aloha efficiency

P(success by given node) = P(node transmits) $\cdot$

P(no other node transmits in $[t_0\text{-}1, t_0]$) $\cdot$

P(no other node transmits in $[t_0, t_0\text{+}1]$)

$= p \cdot (1-p)^{N-1} \cdot (1-p)^{N-1}$

$= p \cdot (1-p)^{2(N-1)}$

… choosing optimum p and then letting $N \rightarrow \infty$ ...

$= 1/(2e) = .18$

even worse than slotted Aloha!

CSMA (Carrier Sense Multiple Access)

CSMA: listen before transmit:

If channel sensed idle: transmit entire frame

- If channel sensed busy, defer transmission

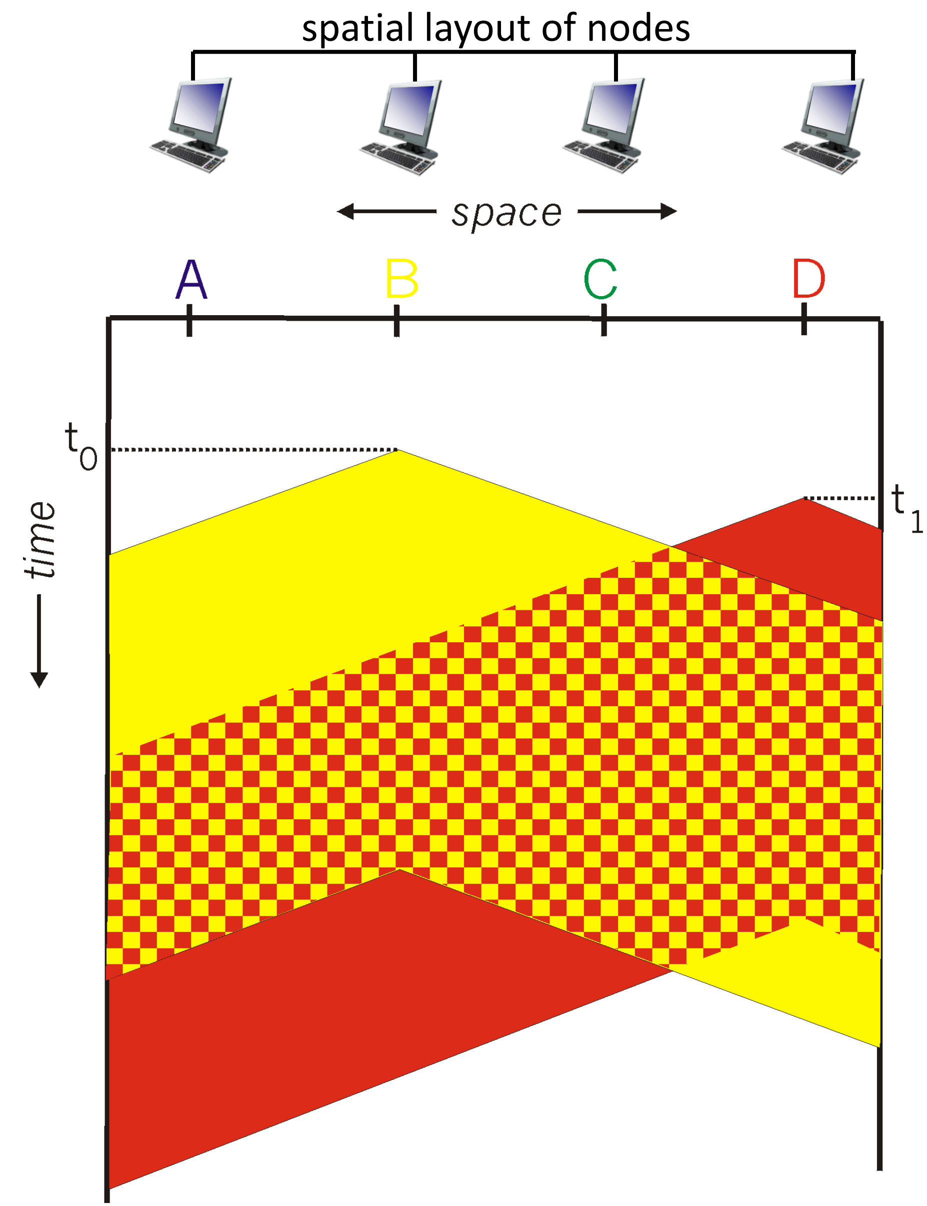
- human analogy: don't interrupt others!

CSMA collisions

collisions can still occur:
propagation delay means two nodes may not hear each other's transmission

collision:
entire packet transmission time wasted

note:
distance & propagation delay play an important role in determining collision probability



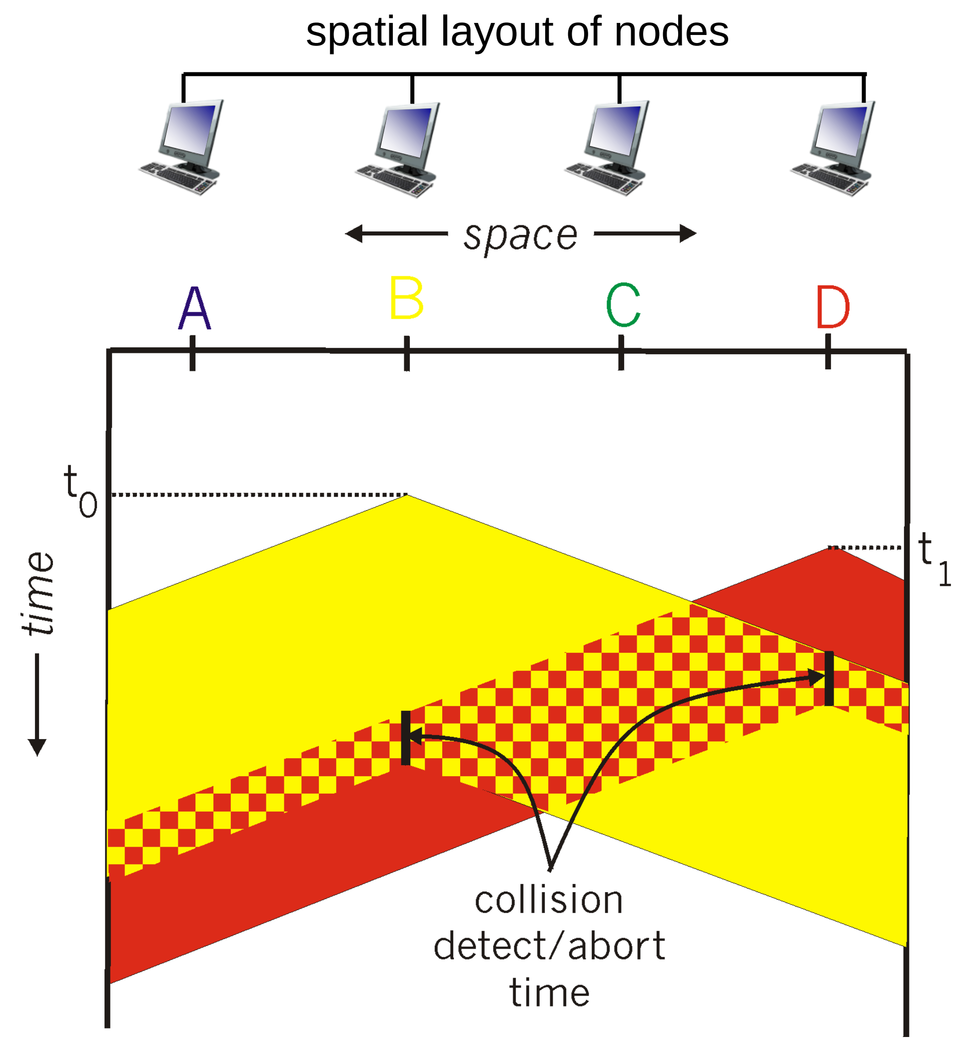
CSMA/CD (Collision Detection)

CSMA/CD: carrier sensing, deferral as in CSMA

- collisions *detected* within short time
- colliding transmissions aborted, reducing channel wastage

- collision detection:
  - easy in wired LANs: measure signal strengths; compare transmitted, received signals
  - difficult in wireless LANs: received signal strength overwhelmed by local transmission strength
- human analogy: the polite conversationalist

CSMA/CD collision detection



Ethernet CSMA/CD algorithm

1. NIC (*network interface card*) receives datagram from network layer, creates frame.
2. If NIC senses channel idle, starts frame transmission. If NIC senses channel busy, waits until channel idle, then transmits.
3. If NIC transmits entire frame without detecting another transmission, NIC is done with frame !
4. If NIC detects another transmission while transmitting, aborts and sends *jam* signal.
5. After aborting, NIC enters *binary (exponential) backoff:*
   - after m^{th} collision, NIC chooses K at random from $\{0,1,2, \ldots, 2^m-1\}$; NIC waits K·512 bit times, returns to Step 2;
   - longer backoff interval with more collisions.

CSMA/CD efficiency

- t_{prop} = max prop delay between 2 nodes in LAN
- t_{trans} = time to transmit max-size frame

$$efficiency = \frac{1}{1 + 5t_{prop}/t_{trans}}$$

- efficiency goes to 1
  - as t_{prop} goes to 0
  - as t_{trans} goes to infinity
- better performance than ALOHA: and simple, cheap, decentralized!

“Taking Turns” MAC protocols

Channel partitioning MAC protocols

- share channel *efficiently* and *fairly* at high load
- inefficient at low load: delay in channel access, 1/N bandwidth allocated even if only 1 active node!

Random access MAC protocols

- efficient at low load: single node can fully utilize channel
- high load: collision overhead

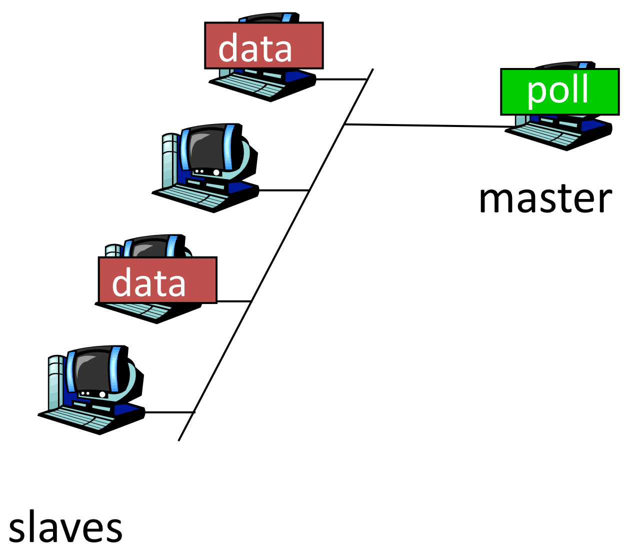
“Taking turns” protocols

look for best of both worlds!

“Taking Turns” MAC protocols

Polling:

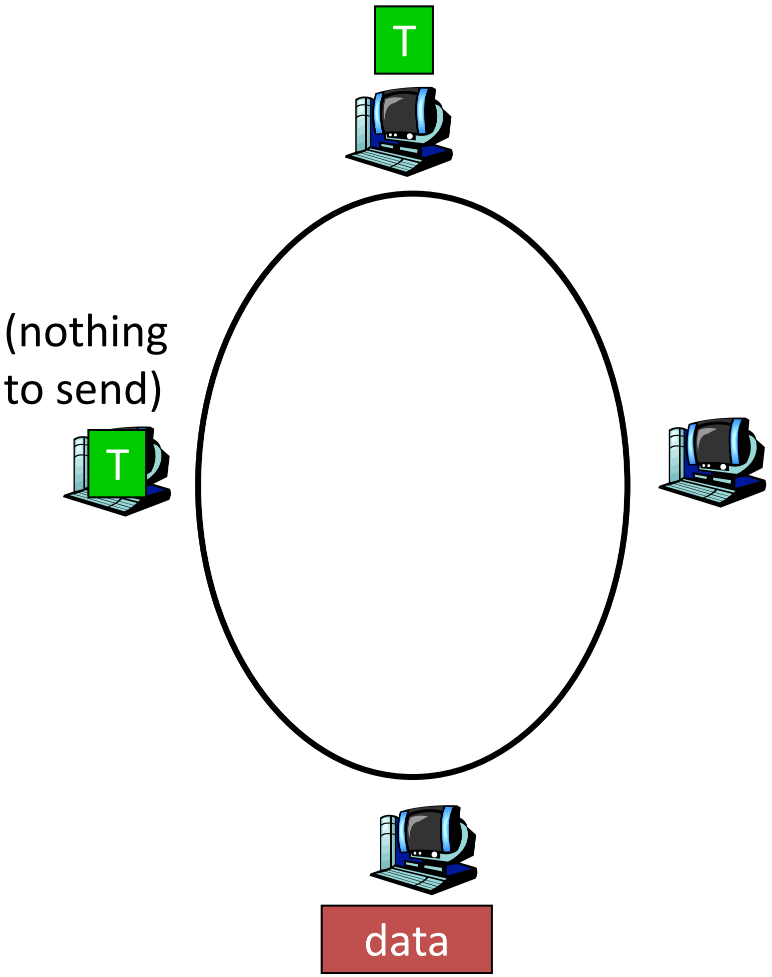
- master node “invites” slave nodes to transmit in turn
- typically used with “dumb” slave devices
- concerns:
  - polling overhead
  - latency
  - single point of failure (master)



“Taking Turns” MAC protocols

Token passing:

- control **token** passed from one node to next sequentially
- token message
- concerns:
  - token overhead
  - latency
  - single point of failure (token)



Summary of MAC protocols

- *channel partitioning,* by time, frequency or code
  - Time Division, Frequency Division, Code Division
- *random access* (dynamic),
  - ALOHA, S-ALOHA, CSMA, CSMA/CD
  - carrier sensing: easy in some technologies (wire), hard in others (wireless)
  - CSMA/CD used in Ethernet
  - CSMA/CA used in 802.11
- *taking turns*
  - polling from central site, token passing
  - Bluetooth, FDDI, Token Ring

A1.4 Routing Algorithms

A1.4a A Link-State Routing Algorithm

Dijkstra's algorithm

- net topology, link costs known to all nodes
  - accomplished via "link state broadcast"
  - all nodes have same info
- computes least cost paths from one node ("source") to all other nodes
  - gives forwarding table for that node
- iterative: after k iterations, know least cost path to k dest.'s

Notation:

- c(x,y): link cost from node x to y; = ∞ if not direct neighbors
- D(v): current value of cost of path from source to dest. v
- p(v): predecessor node along path from source to v
- N': set of nodes whose least cost path definitively known

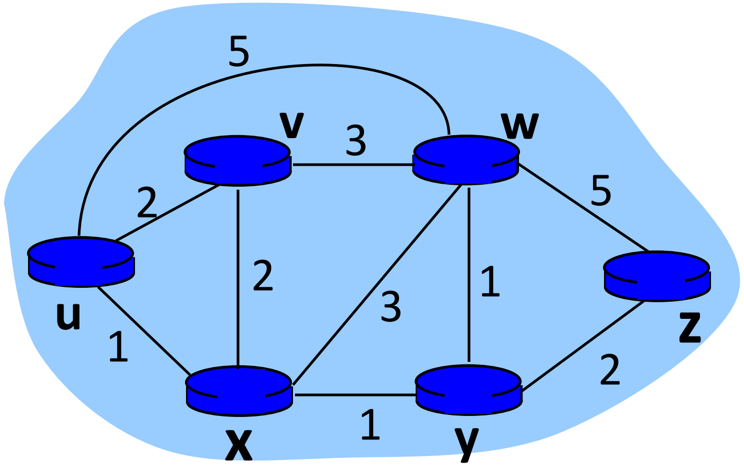
Dijkstra's Algorithm

```
Initialization:
  N' = {u}
  for all nodes v
    if v adjacent to u
        then D(v) = c(u,v)
    else D(v) = ∞

 Loop
   find w not in N' such that D(w) is a minimum
    add w to N'
    update D(v) for all v adjacent to w and not in N' :
        D(v) = min( D(v), D(w) + c(w,v) )
    /* new cost to v is either old cost to v or known
     shortest path cost to w plus cost from w to v */
 until all nodes in N'
```

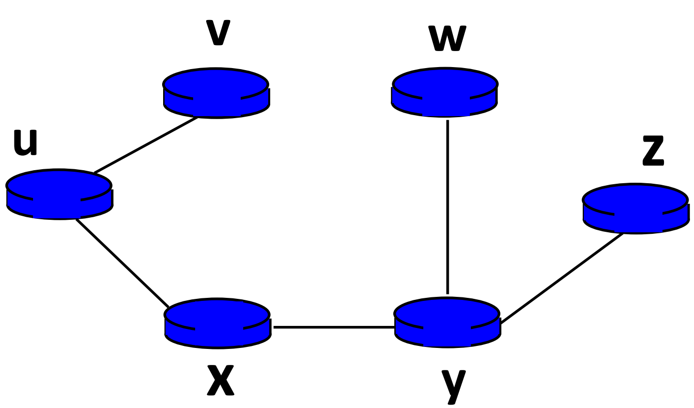
Dijkstra's algorithm: example

Step	N'	D(v),p(v)	D(w),p(w)	D(x),p(x)	D(y),p(y)	D(z),p(z)
0	u	2,u	5,u	1,u	∞	∞
1	ux	2,u	4,x		2,x	∞
2	uxy	2,u	3,y			4,y
3	uxyv		3,y			4,y
4	uxyvw					4,y
5	uxyvwz					



Dijkstra’s algorithm: example (2)

Resulting shortest-path tree from u:



Resulting forwarding table in u:

destination	link
v	(u,v)
x	(u,x)
y	(u,x)
w	(u,x)
z	(u,x)

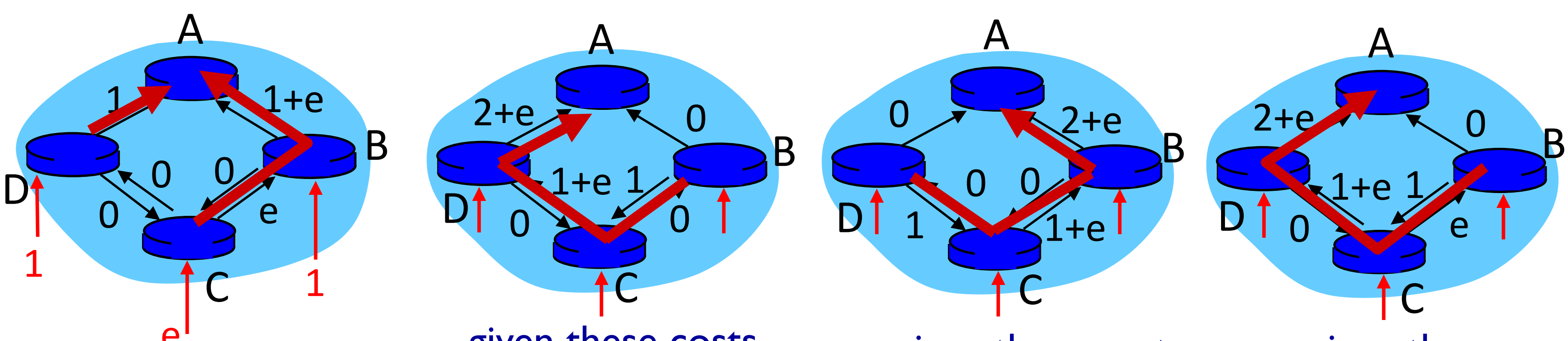
Dijkstra’s algorithm, discussion

Algorithm complexity: n nodes

- each iteration: need to check all nodes, w, not in N‘
- n(n+1)/2 comparisons: $O(n^2)$
- more efficient implementations possible: $O(n \cdot \log(n))$

Oscillations possible:

- e.g., support link cost equals amount of carried traffic:



initially

given these costs, find new routing…. resulting in new costs

given these costs, find new routing…. resulting in new costs

given these costs, find new routing…. resulting in new costs

A1.4b Distance Vector Algorithm

Bellman-Ford Equation (dynamic programming)

Let

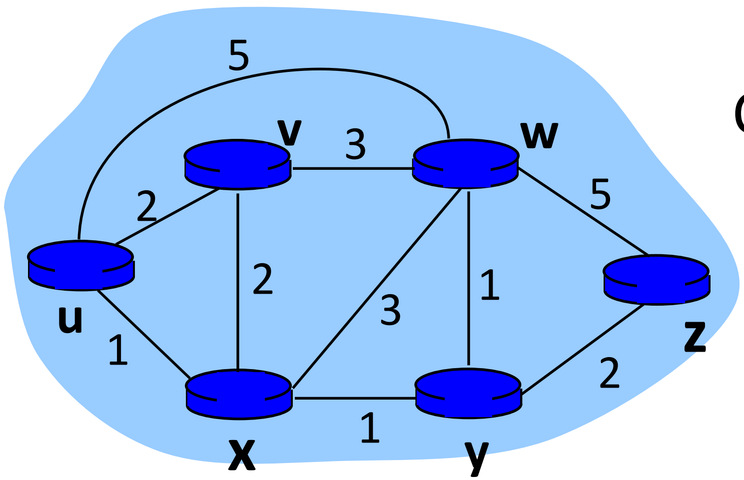
$d_x(y)$:= cost of least-cost path from x to y

then

$$\boxed{d_x(y) = \min_{v} \{ c(x,v) + d_v(y) \}}$$

where *min* is taken over all neighbors v of x, and c(x,v) denotes cost to neighbor v.

Bellman-Ford (B-F) example



Clearly, $d_v(z) = 5$, $d_x(z) = 3$, $d_w(z) = 3$

B-F equation says:

$$
\begin{aligned}
d_u(z) = \min \{ & c(u,v) + d_v(z), \\
& c(u,x) + d_x(z), \\
& c(u,w) + d_w(z) \} \\
= \min \{ & 2 + 5, \\
& 1 + 3, \\
& 5 + 3\} = 4
\end{aligned}
$$

Node that achieves minimum is next hop in shortest path ➜ used in forwarding table

Distance Vector Algorithm (3)

- $D_x(y)$ = estimate of least cost from x to y
  - x maintains distance vector $\mathbf{D}_x = [D_x(y): y \in N]$

- node x:
  - knows cost to each neighbor v: $c(x,v)$
  - maintains its neighbors' distance vectors. For each neighbor v, x maintains $\mathbf{D}_v = [D_v(y): y \in N]$

Distance vector (DV) algorithm (4)

Basic idea:

- From time-to-time, each node sends its own distance vector estimate to neighbors
- Asynchronous
- When a node x receives new DV estimate from neighbor, it updates its own DV using B-F equation:

$$D_x(y) \leftarrow \min_v \{c(x,v) + D_v(y)\} \quad \text{for each node } y \in N$$

- Under minor, natural conditions, the estimate $D_x(y)$ *converge to the actual least cost* $d_x(y)$

Distance Vector Algorithm (5)

Iterative, asynchronous:

each local iteration caused by:

- local link cost change
- DV update message from neighbor

Distributed:

- each node notifies neighbors *only* when its DV changes
  – neighbors then notify their neighbors if necessary

Each node:

wait for (change in local link cost or msg from neighbor)

recompute estimates

if DV to any dest has changed, *notify* neighbors

$D_x(y) = \min\{c(x,y) + D_y(y), c(x,z) + D_z(y)\}$
$= \min\{2+0 , 7+1\} = 2$

$D_x(z) = \min\{c(x,y) + D_y(z), c(x,z) + D_z(z)\}$
$= \min\{2+1 , 7+0\} = 3$

node x table

from \ cost to	x	y	z
x	0	2	7
y	∞	∞	∞
z	∞	∞	∞

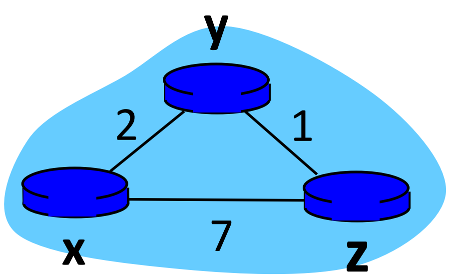
from \ cost to	x	y	z
x	0	2	3
y	2	0	1
z	7	1	0

node y table

from \ cost to	x	y	z
x	∞	∞	∞
y	2	0	1
z	∞	∞	∞

node z table

from \ cost to	x	y	z
x	∞	∞	∞
y	∞	∞	∞
z	7	1	0



time

$D_x(y) = \min\{c(x,y) + D_y(y), c(x,z) + D_z(y)\}$
$= \min\{2+0 , 7+1\} = 2$

$D_x(z) = \min\{c(x,y) + D_y(z), c(x,z) + D_z(z)\}$
$= \min\{2+1 , 7+0\} = 3$

node x table

from \ *cost to*	x	y	z
x	0	2	7
y	∞	∞	∞
z	∞	∞	∞

from \ *cost to*	x	y	z
x	0	2	3
y	2	0	1
z	7	1	0

from \ *cost to*	x	y	z
x	0	2	3
y	2	0	1
z	3	1	0

node y table

from \ *cost to*	x	y	z
x	∞	∞	∞
y	2	0	1
z	∞	∞	∞

from \ *cost to*	x	y	z
x	0	2	7
y	2	0	1
z	7	1	0

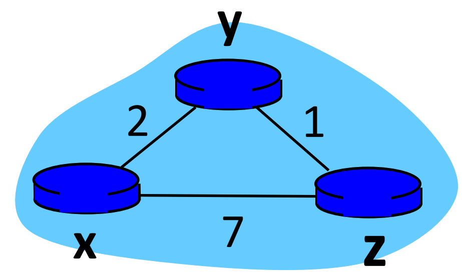
from \ *cost to*	x	y	z
x	0	2	3
y	2	0	1
z	3	1	0

node z table

from \ *cost to*	x	y	z
x	∞	∞	∞
y	∞	∞	∞
z	7	1	0

from \ *cost to*	x	y	z
x	0	2	7
y	2	0	1
z	3	1	0

from \ *cost to*	x	y	z
x	0	2	3
y	2	0	1
z	3	1	0

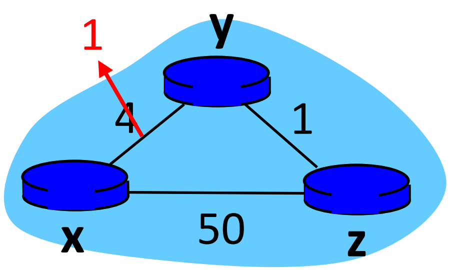


time

Distance Vector: link cost changes

Link cost changes:

- node detects local link cost change
- updates routing info, recalculates distance vector
- if DV changes, notify neighbors



"good news travels fast"

At time t_0, y detects the link-cost change, updates its DV, and informs its neighbors.

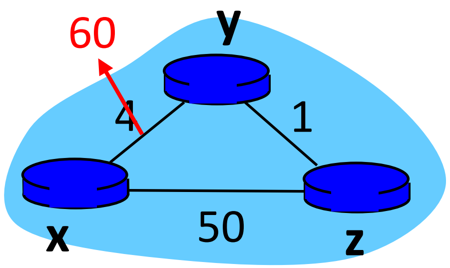
At time t_1, z receives the update from y and updates its table. It computes a new least cost to x and sends its neighbors its DV.

At time t_2, y receives z's update and updates its distance table. y's least costs do *not* change and hence y does *not* send any message to z.

Distance Vector: link cost changes

Link cost changes:

- good news travels fast
- *bad news travels slow* - "count to infinity" problem!
- 44 iterations before algorithm stabilizes: see text (Kurose/Ross' book)



Poisoned reverse:

- If Z routes through Y to get to X :
  - Z tells Y its (Z's) distance to X is infinite (so Y won't route to X via Z)
- will this completely solve count to infinity problem?

Comparison of LS and DV algorithms

Message complexity

- LS: with n nodes, E links, O(nE) msgs sent
- DV: exchange between neighbors only
  - convergence time varies

Speed of Convergence

- LS: $O(n^2)$ algorithm requires O(nE) msgs
  - may have oscillations
- DV: convergence time varies
  - may be routing loops
  - count-to-infinity problem

Robustness: what happens if router malfunctions?

LS:

- node can advertise incorrect *link* cost
- each node computes only its *own* table

DV:

- DV node can advertise incorrect *path* cost
- each node's table used by others
  - error propagate thru network

Part A “Wireless and Mobile Networks”

A1. **Some Basics of Mobile Networks**

A2. **Wireless Local Networks**
- A2.1 IEEE 802.11 Architecture
- A2.2 IEEE 802.11 MAC Protocol
- A2.3 Syntax and Semantics of IEEE 802.11 Frames
- A2.4 Mobility in the Same IP Subnet
- A2.5 Advanced Features in 802.11
- A2.6 Beyond 802.11: Bluetooth and WiMAX

A3. **Cellular Networks and Mobile Internet Access**

A4. **Mobility Management and Mobile IP**

A5. **Satellite Communications**

A6. **Sensor Networks**

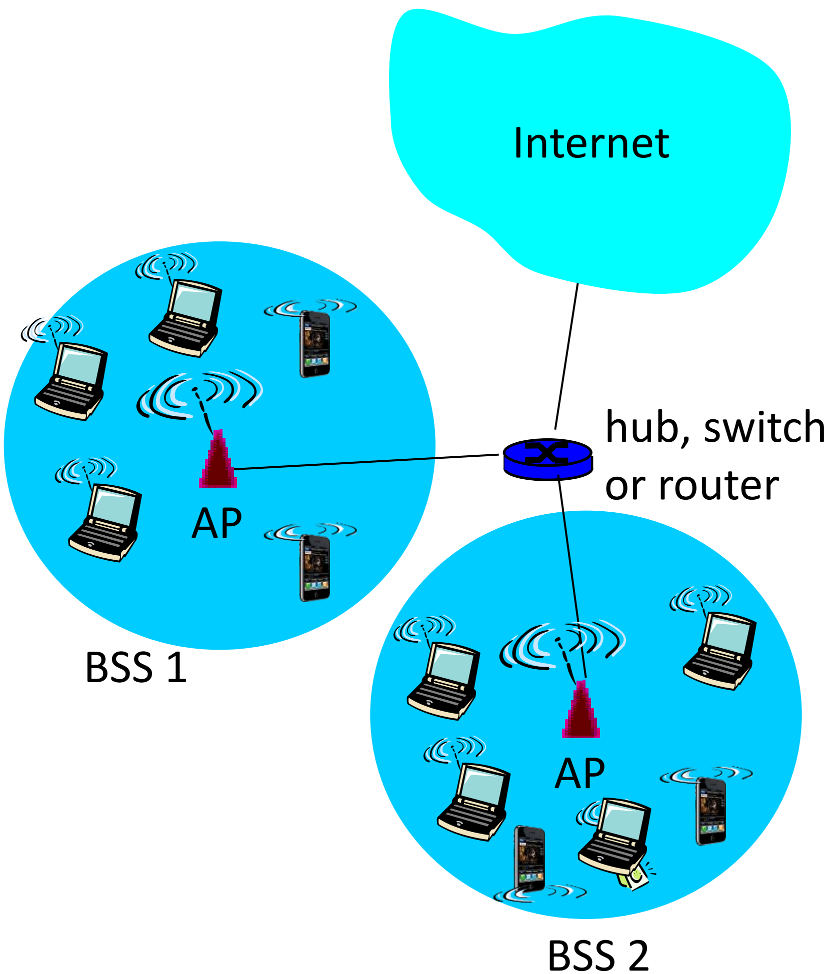
A.2 Wireless Local Networks

IEEE 802.11 Wireless LAN

- 802.11b
  - 2.4-5 GHz unlicensed spectrum
  - up to 11 Mbps
  - direct sequence spread spectrum (DSSS) in physical layer
    - all hosts use same chipping code
- 802.11a
  - 5-6 GHz range
  - up to 54 Mbps
- 802.11g
  - 2.4-5 GHz range
  - up to 54 Mbps
- 802.11n: multiple antennae
  - 2.4-5 GHz range
  - up to 200 Mbps

- all use CSMA/CA for multiple access
- all have base-station and ad-hoc network versions

A2.1 IEEE 802.11 Architecture

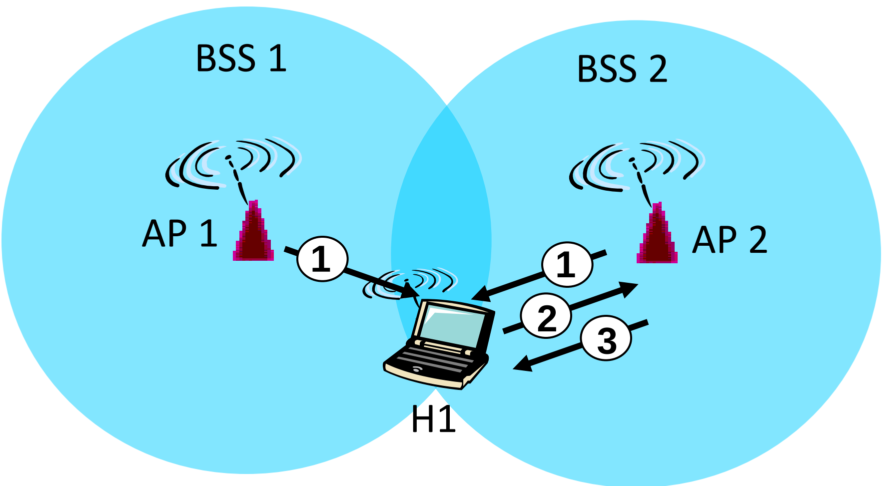


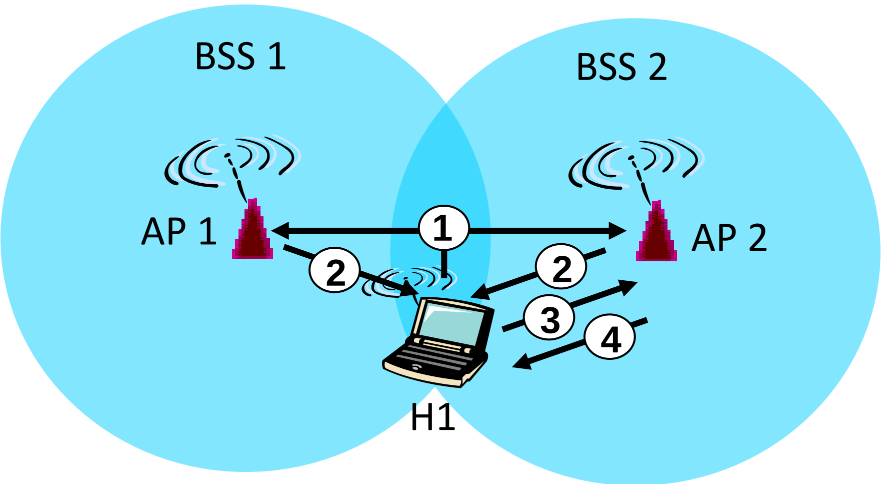
- wireless host communicates with base station
  - base station = access point (AP)
- Basic Service Set (BSS) (aka "cell") in infrastructure mode contains:
  - wireless hosts
  - access point (AP): base station
  - ad hoc mode: hosts only

802.11: Channels, association

- 802.11b: 2.4 GHz-2.485 GHz spectrum divided into 11 channels at different frequencies
  - AP admin chooses frequency for AP
  - interference possible: channel can be same as that chosen by neighboring AP!
- host: must *associate* with an AP
  - scans channels, listening for *beacon frames* containing AP's name (SSID) and MAC address
  - selects AP to associate with
  - may perform authentication
  - will typically run DHCP to get IP address in AP's subnet

802.11: passive/active scanning



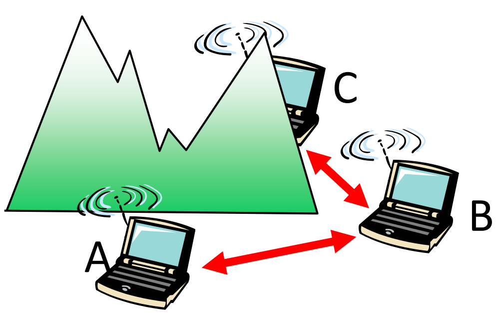


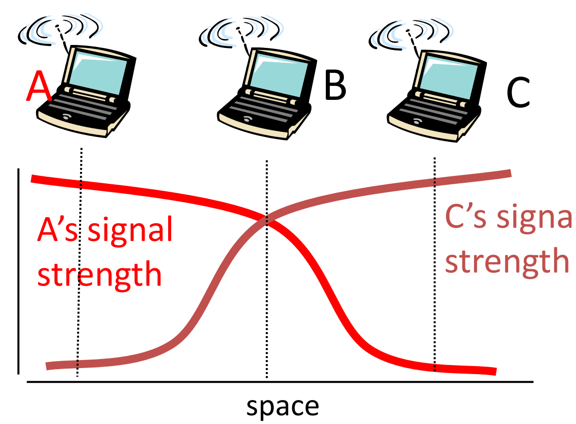
Passive Scanning :
(1) Beacon frames sent from APs
(2) Association Request frame sent: H1 to selected AP
(3) Association Response frame sent: To H1 from selected AP

Active Scanning :
(1) Probe Request frame broadcast from H1
(2) Probes response frame sent from APs
(3) Association Request frame sent: H1 to selected AP
(4) Association Response frame sent: To H1 from selected AP

IEEE 802.11: multiple access

- avoid collisions: 2^+ nodes transmitting at same time
- 802.11: CSMA - sense before transmitting
  - don't collide with ongoing transmission by other node
- 802.11: *no* collision detection!
  - difficult to receive (sense collisions) when transmitting due to weak received signals (fading)
  - can't sense all collisions in any case: hidden terminal, fading
  - goal: *avoid collisions:* CSMA/C(ollision)A(voidance)





A2.2 IEEE 802.11 MAC Protocol (i.e. CSMA/CA)

802.11 sender

(1) if sense channel idle for **DIFS** then

transmit entire frame (no CD)

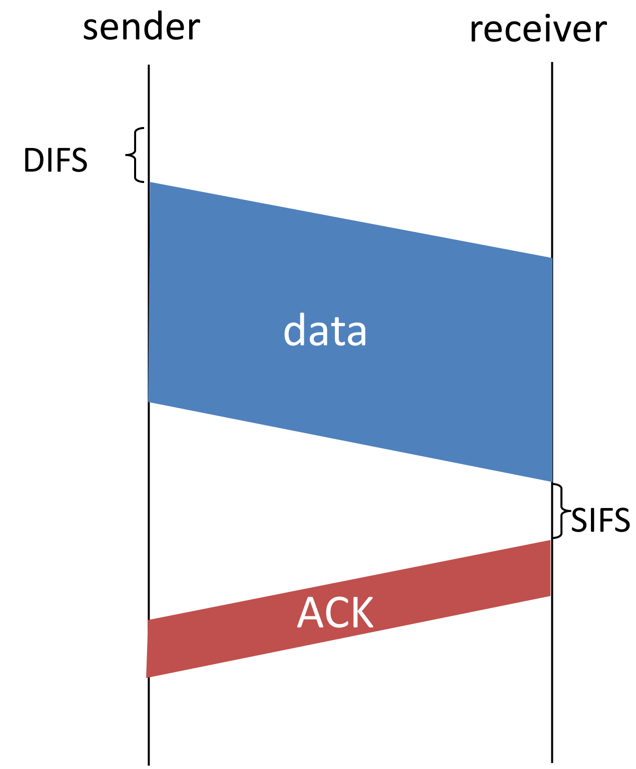
(2) if sense channel busy then

start random backoff time

timer counts down while channel idle

transmit when timer expires

if no ACK, increase random backoff interval, repeat (2)



802.11 receiver

- if frame received OK

return ACK after **SIFS** (ACK needed due to hidden terminal problem) ; SIFS < DISF

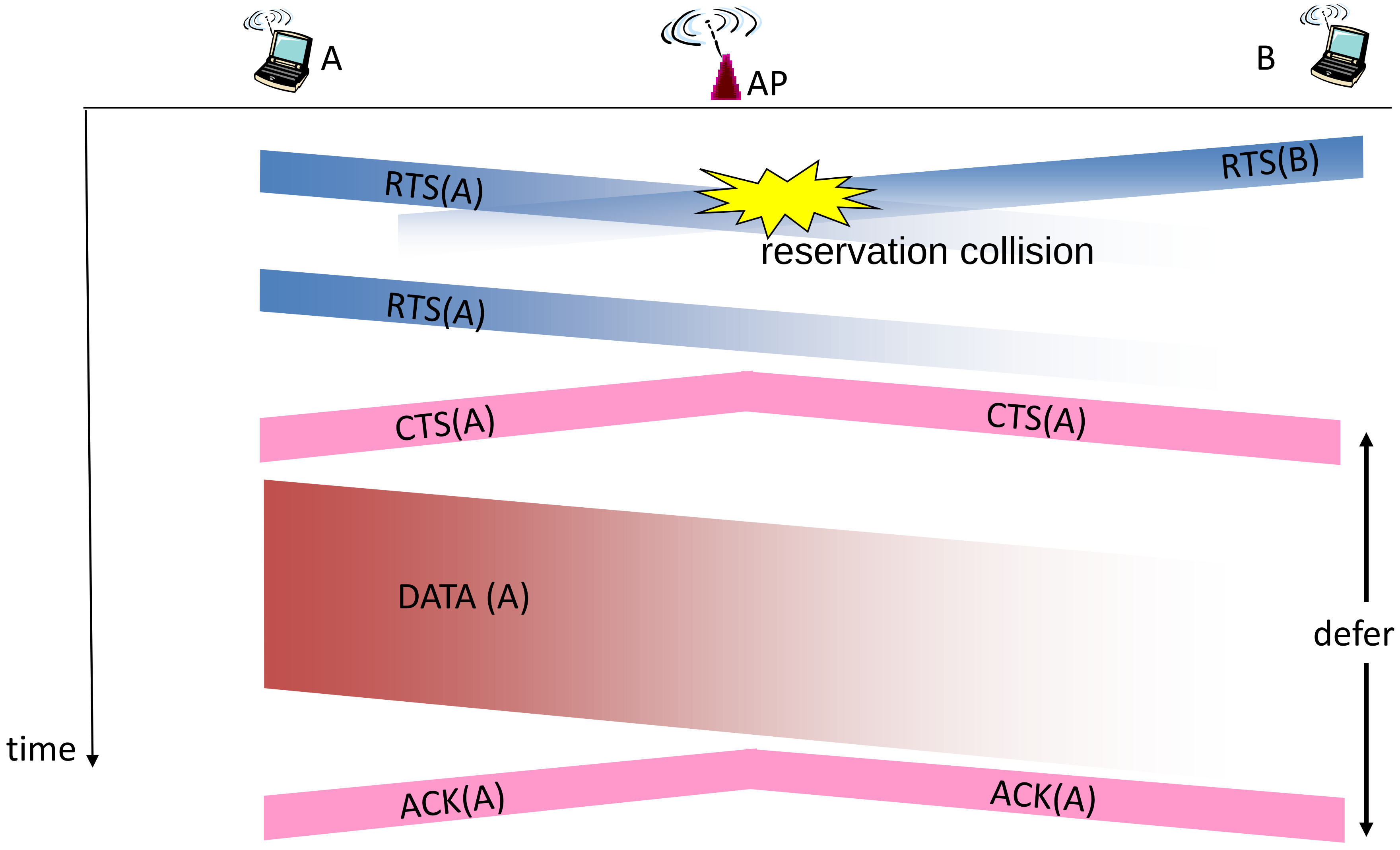
Avoiding collisions (more)

idea: allow sender to “reserve” channel rather than random access of data frames: avoid collisions of long data frames

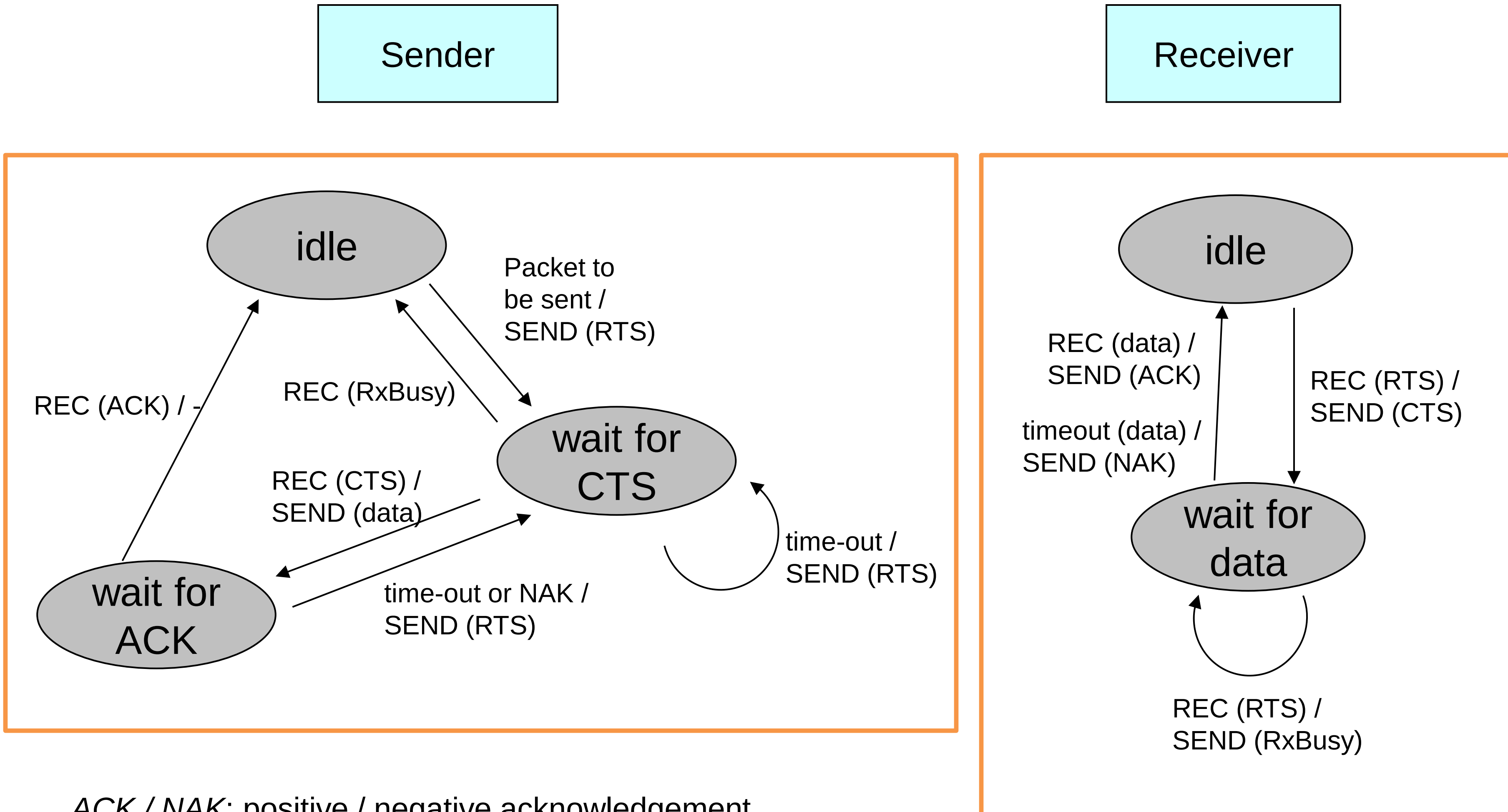
- sender first transmits *small* request-to-send (RTS) packets to BS using CSMA
  - RTSs may still collide with each other (but they’re short)
- BS broadcasts clear-to-send (CTS) in response to RTS
- CTS heard by all nodes
  - sender transmits data frame
  - other stations defer transmissions

Avoid data frame collisions completely using small reservation packets!
but: reservation packets may still collide

Collision Avoidance: RTS-CTS exchange



Formal Description of the RTS/CTS Mechanism



ACK / NAK: positive / negative acknowledgement
RxBusy: receiver busy

A2.3 Syntax and Semantics of IEEE 802.11 Frames

802.11 frame: addressing

2	2	6	6	6	2	6	0 - 2312	4
frame control	duration	address 1	address 2	address 3	seq control	address 4	payload	CRC

Address 1: MAC address of wireless host or AP to receive this frame

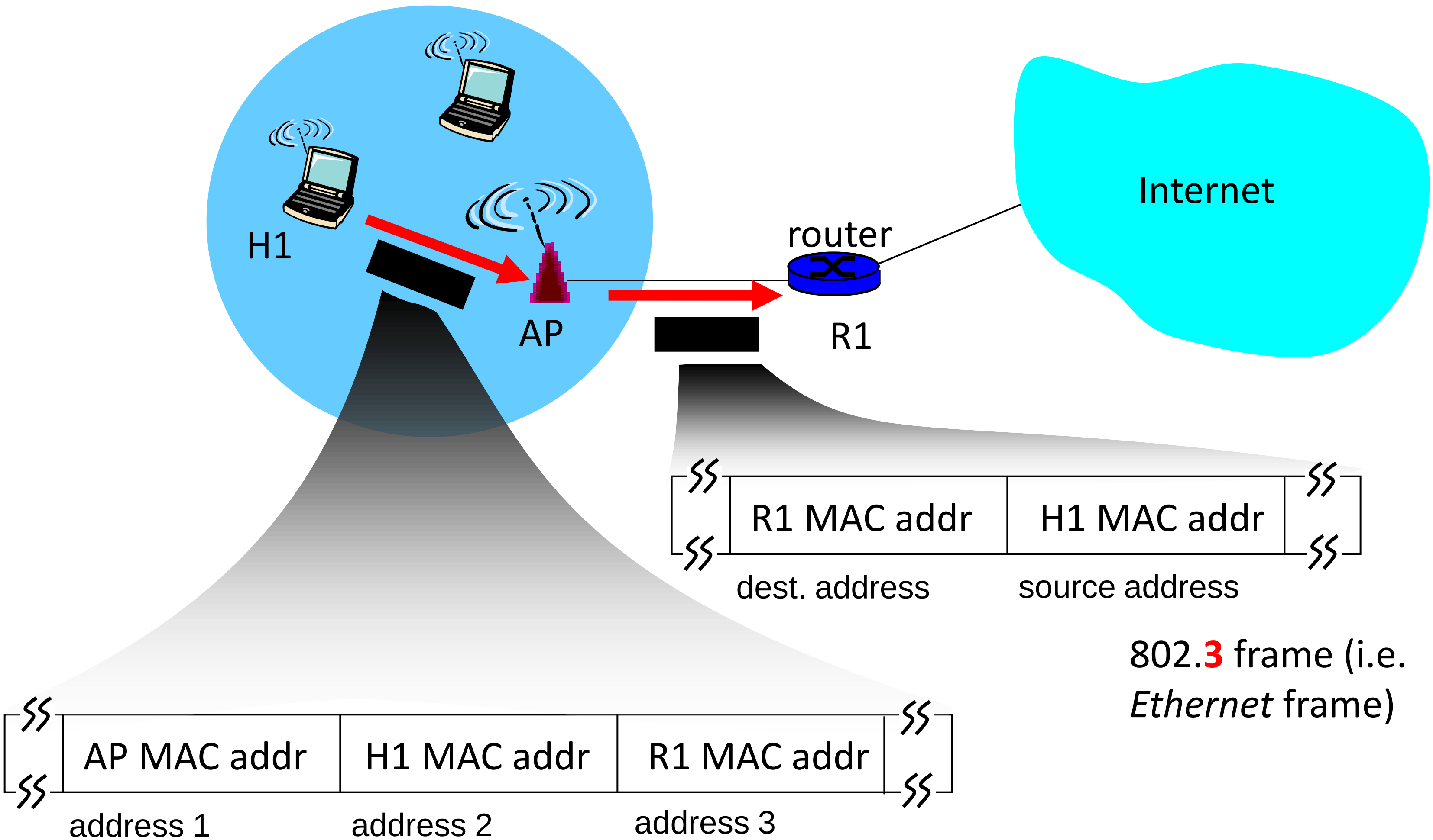
Address 2: MAC address of wireless host or AP transmitting this frame

Address 3: MAC address of router interface to which AP is attached

Address 4: used only in ad hoc mode

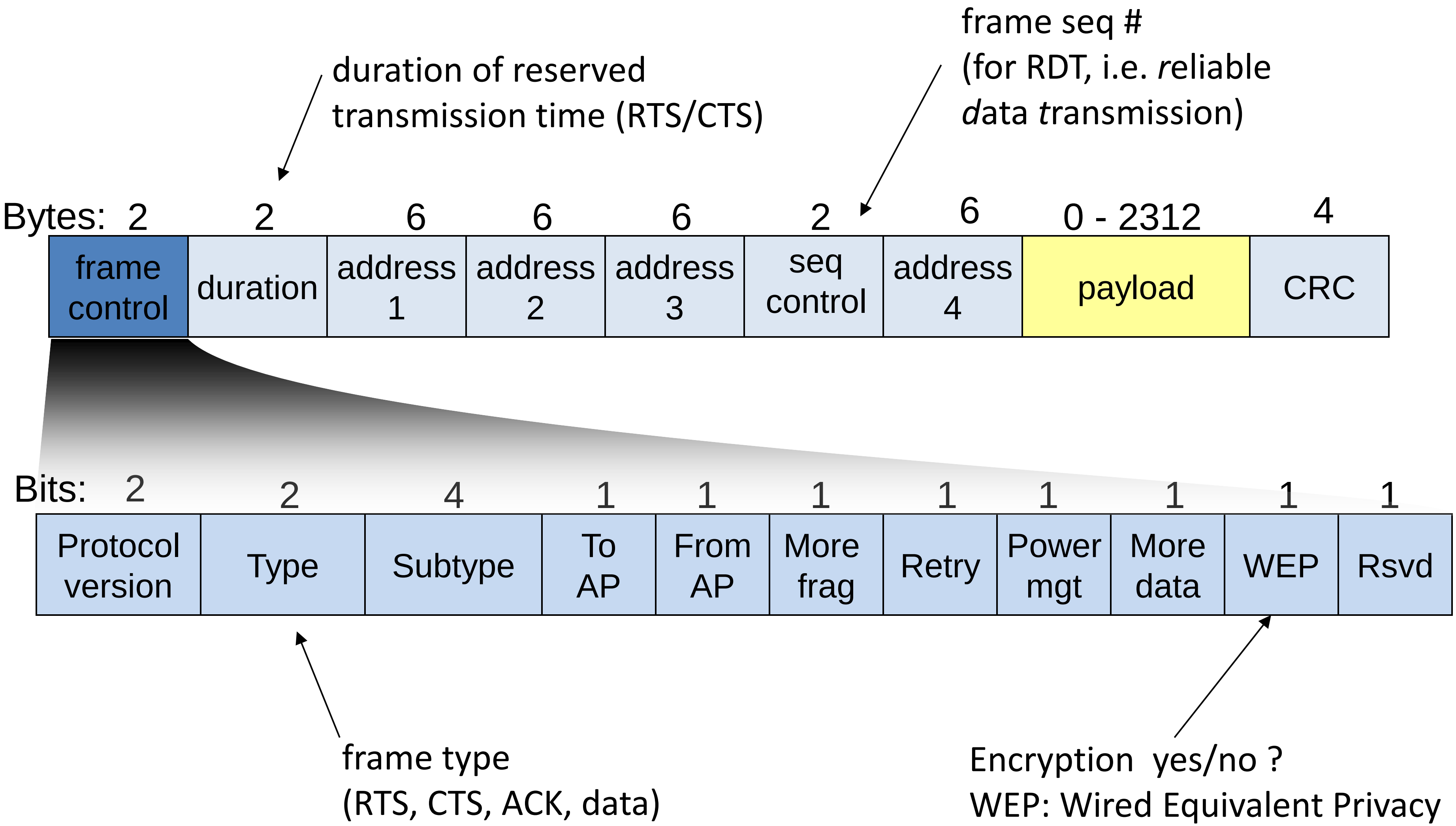
Please note: Semantics of addresses dependent on type of communication path used (e.g. communication within just one cell or not)

802.11 frame: addressing



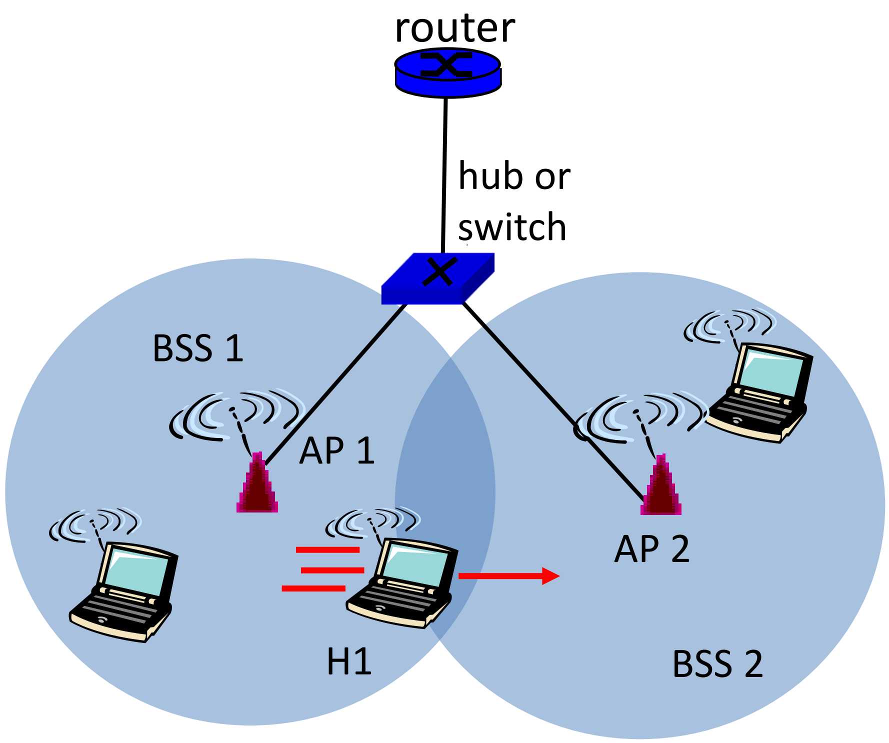
802.11 frame

802.11 frame: more



A2.4 Mobility in the Same IP Subnet

- H1 remains in same IP subnet: IP address can remain same
- switch: which AP is associated with H1?
  - self-learning (Ch. 5 of [KuR 12]): switch will see frame from H1 and “remember” which switch port can be used to reach H1

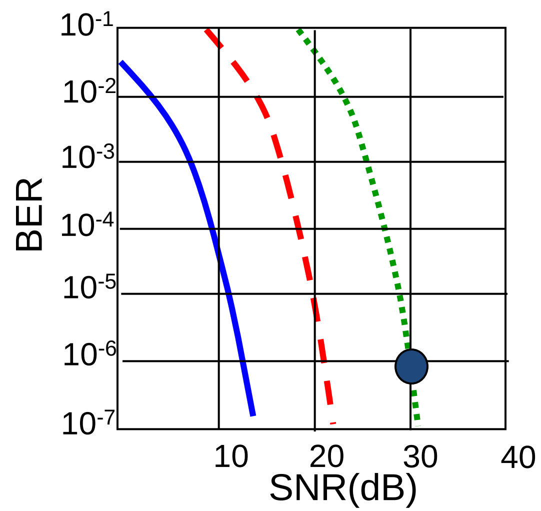


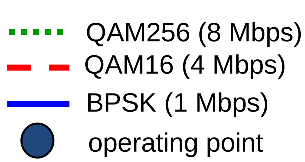
A2.5 Advanced Features in 802.11

802.11: advanced capabilities

Rate Adaptation

- base station, mobile dynamically change transmission rate (physical layer modulation technique) as mobile moves, SNR varies





1. SNR decreases, BER increase as node moves away from base station

2. When BER becomes too high, switch to lower transmission rate but with lower BER

802.11: advanced capabilities

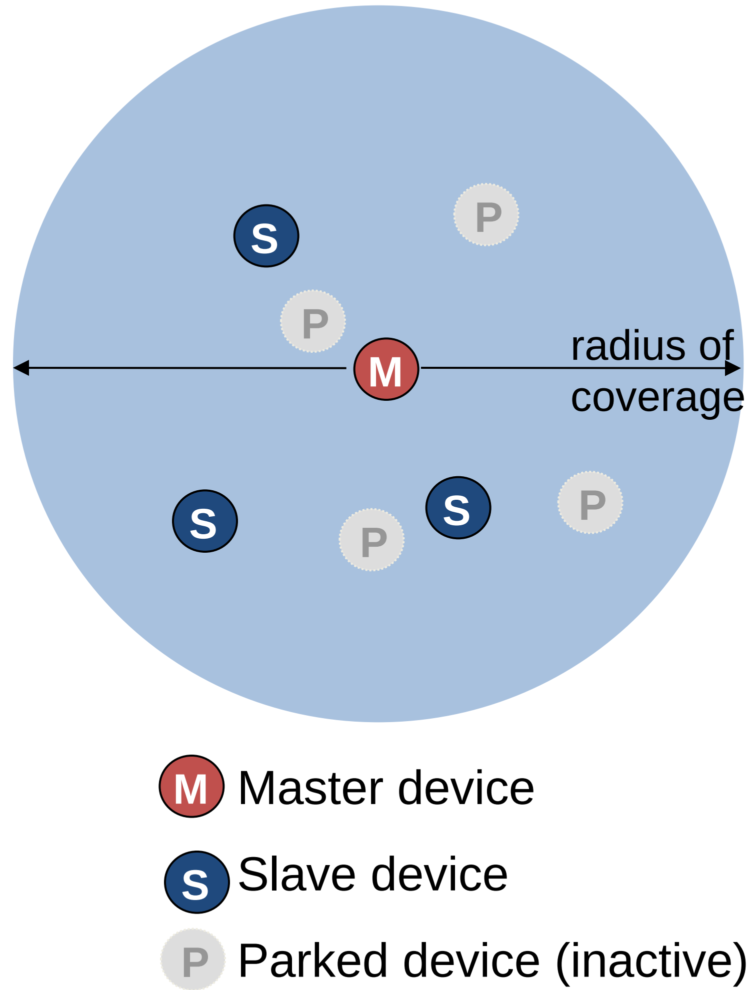
Power Management

- node-to-AP: “I am going to sleep until next beacon frame”
  - AP knows not to transmit frames to this node
  - node wakes up before next beacon frame
- beacon frame: contains list of mobiles with AP-to-mobile frames waiting to be sent
  - node will stay awake if AP-to-mobile frames to be sent; otherwise sleep again until next beacon frame

A2.6 Beyond 802.11: Bluetooth and WiMAX

802.15: personal area network

- less than 10 m diameter
- replacement for cables (mouse, keyboard, headphones)
- ad hoc: no infrastructure
- master/slaves:
  - slaves request permission to send (to master)
  - master grants requests
- 802.15: evolved from Bluetooth specification
  - 2.4-2.5 GHz radio band
  - up to 721 kbps

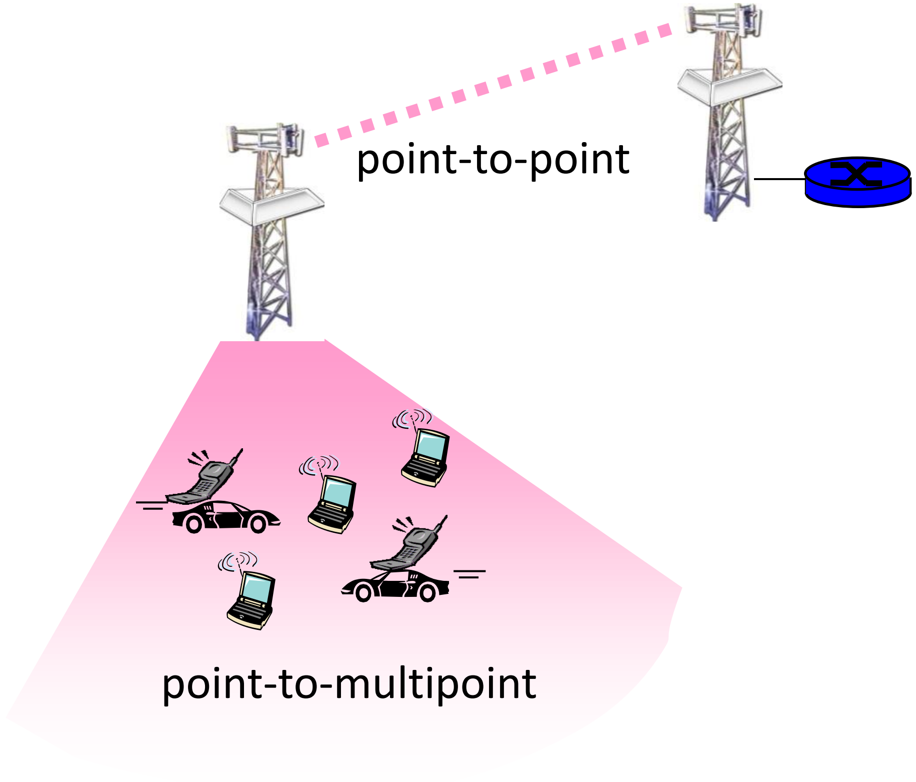


Comparision between IEEE 802.11 and Bluetooth

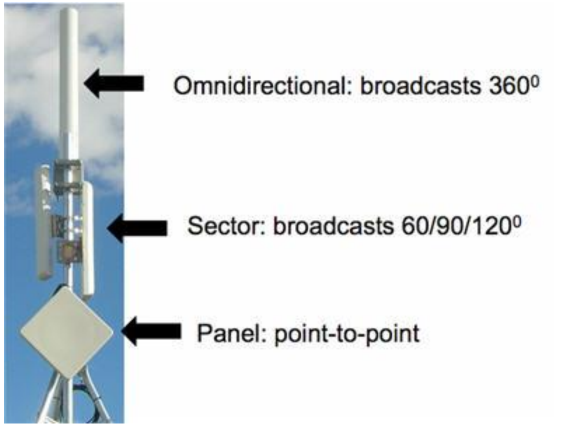
Criterion	IEEE 802.11b/g	IEEE 802.11a	Bluetooth
Frequency	2,4 GHz	5 GHz	2,4 GHz
Max. data rate	11/54 Mbit/s	54 Mbit/s	< 1 Mbit/s
Throughput (user data)	6/34 Mbit/s	34 Mbit/s	< 1 Mbit/s
Medium access control (MAC)	CSMA/CA	CSMA/CA	centralized
Frequency management	none	802.11h	FHSS (frequency hopping spread spectrum)
Authentification	none / 802.1x	none / 802.1x	yes
Encryption	WEP (Wired Equivalent Privacy) 802.11i	WEP 802.11i	yes
QoS support	optional (PCF)	optional (PCF)	flow spec. isochronous
Type of connections	connectionless	connectionless	connection-oriented
Number of usable channels	3	12 (US)	flexible – increasing interferences
Typical transmission power of sender	100 mW	0,05/0,25/1 W TPC with 802.11h (TPC: transmission power ctrl.)	1/2,5/100 m W
Error control	ARQ	ARQ, FEC (PHY)	ARQ, FEC (MAC)

802.16: WiMAX

- like 802.11 & cellular: base station model
  - transmissions to/from base station by hosts with omnidirectional antenna
  - base station-to-base station backhaul with point-to-point antenna

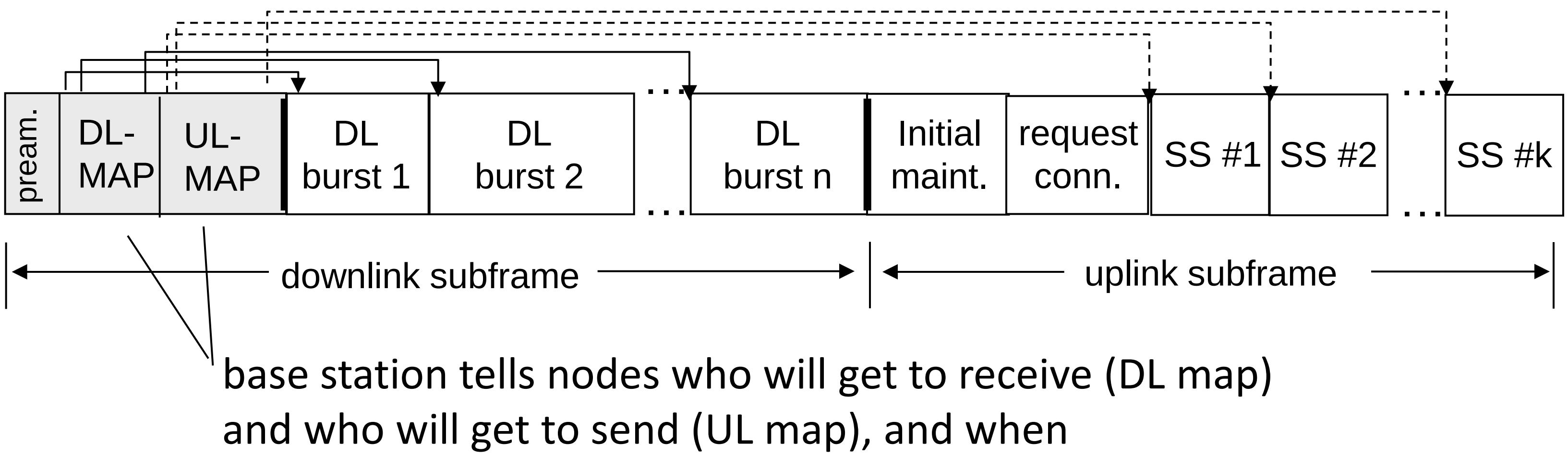


- unlike 802.11:
  - range ≈ 6 miles ("city rather than coffee shop")
  - ≈ 30 - 40 Mbps [currently (2011): up to 1 Gbps for *fixed* stations]



802.16: WiMAX: downlink, uplink scheduling

- transmission frame
  - down-link (DL) subframe: base station to node
  - uplink (UL) subframe: node to base station



- WiMAX standard provides mechanism for scheduling, but not scheduling algorithm

Part A “**Wireless and Mobile Networks**”

A3. Cellular Networks and Mobile Internet Access
A3.1 An Overview of Cellular Architecture

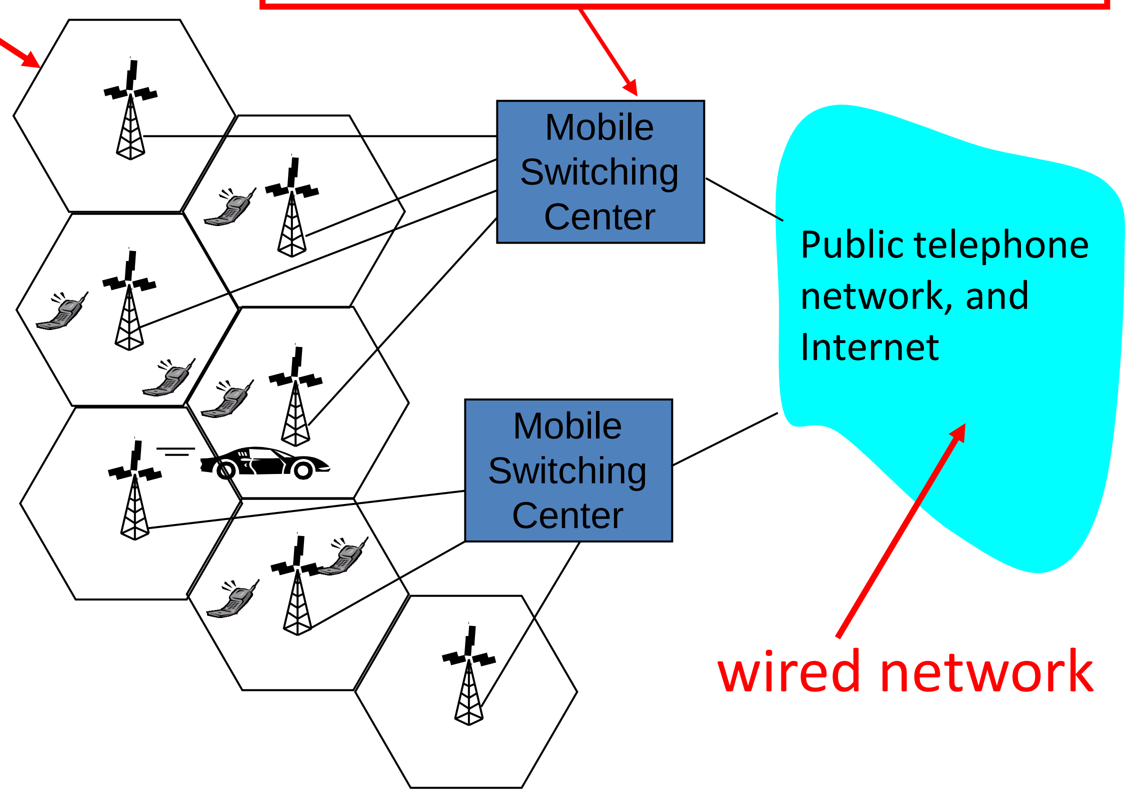
Components of cellular network architecture

MSC

- connects cells to wide area net
- manages call setup (more later!)
- handles mobility (more later!)

cell

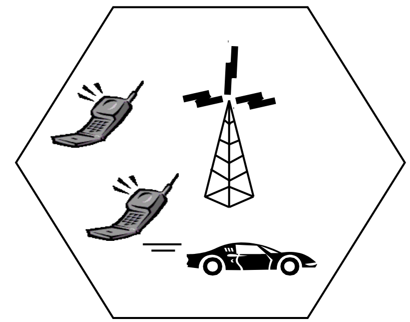
- covers geographical region
- *base station* (BS) analogous to 802.11 AP
- *mobile users* attach to network through BS
- *air-interface:* physical and link layer protocol between mobile and BS

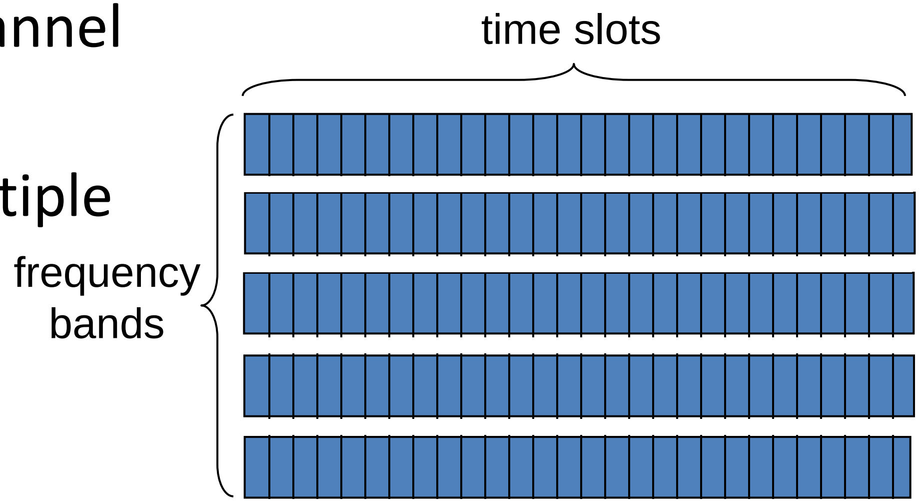


Cellular networks: the first hop

Two techniques for sharing mobile-to-BS radio spectrum

- combined FDMA/TDMA: divide spectrum in frequency channels, divide each channel into time slots
- CDMA: code division multiple access



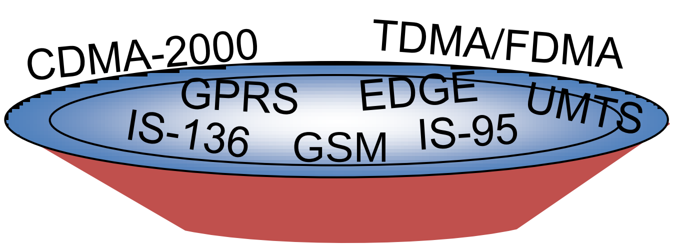


A3.2 Cellular Standards and Technologies: A Brief Survey

Cellular standards

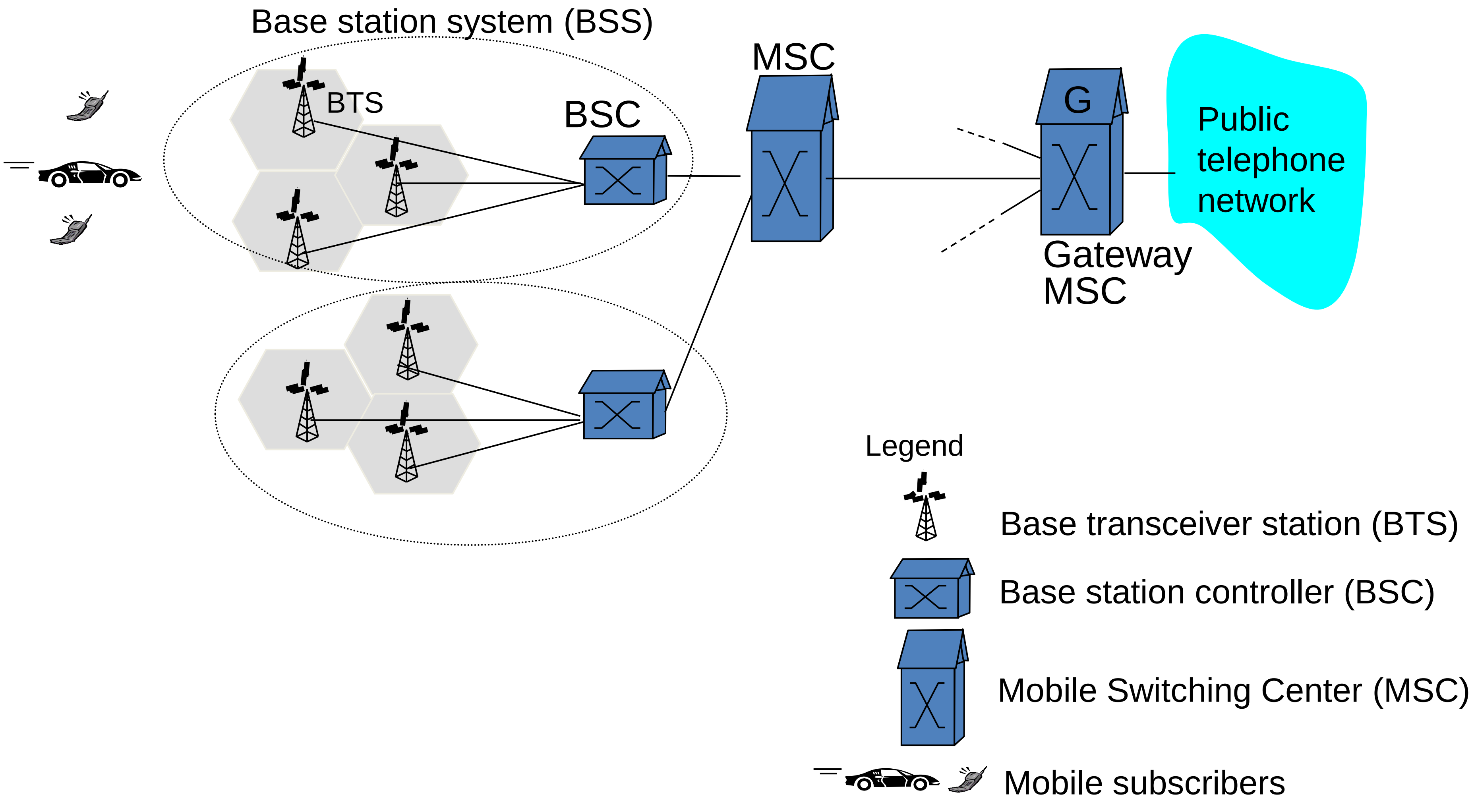
2G systems: voice channels

- IS-136 TDMA: combined FDMA/TDMA (North America)
- GSM (Global System for Mobile communications): combined FDMA/TDMA
  - most widely deployed
- IS-95 CDMA: code division multiple access



Don't drown in a bowl of alphabet soup: use this for reference only

2G (voice) network architecture



Cellular standards: brief survey

2.5 G systems: voice and data channels

- for those who can't wait for 3G service: 2G extensions
- *G*eneral *P*acket *R*adio *S*ervice (GPRS)
  - evolved from GSM
  - data sent on multiple channels (if available)
- *E*nhanced *D*ata rates for *G*lobal *E*volution (EDGE)
  - also evolved from GSM, using enhanced modulation
  - data rates up to 384 kbps
- CDMA-2000 (phase 1)
  - data rates up to 144 kbps
  - evolved from IS-95

Cellular standards: brief survey

3G systems: voice/data

- Universal Mobile Telecommunications Service (UMTS)
  - data service: High Speed Uplink/Downlink Packet Access (HSUPA/HSDPA): 3 Mbps
- CDMA-2000: CDMA in TDMA slots
  - data service: 1xEvolution Data Optimized (1xEVDO) up to 14 Mbps

4G systems: still higher speed

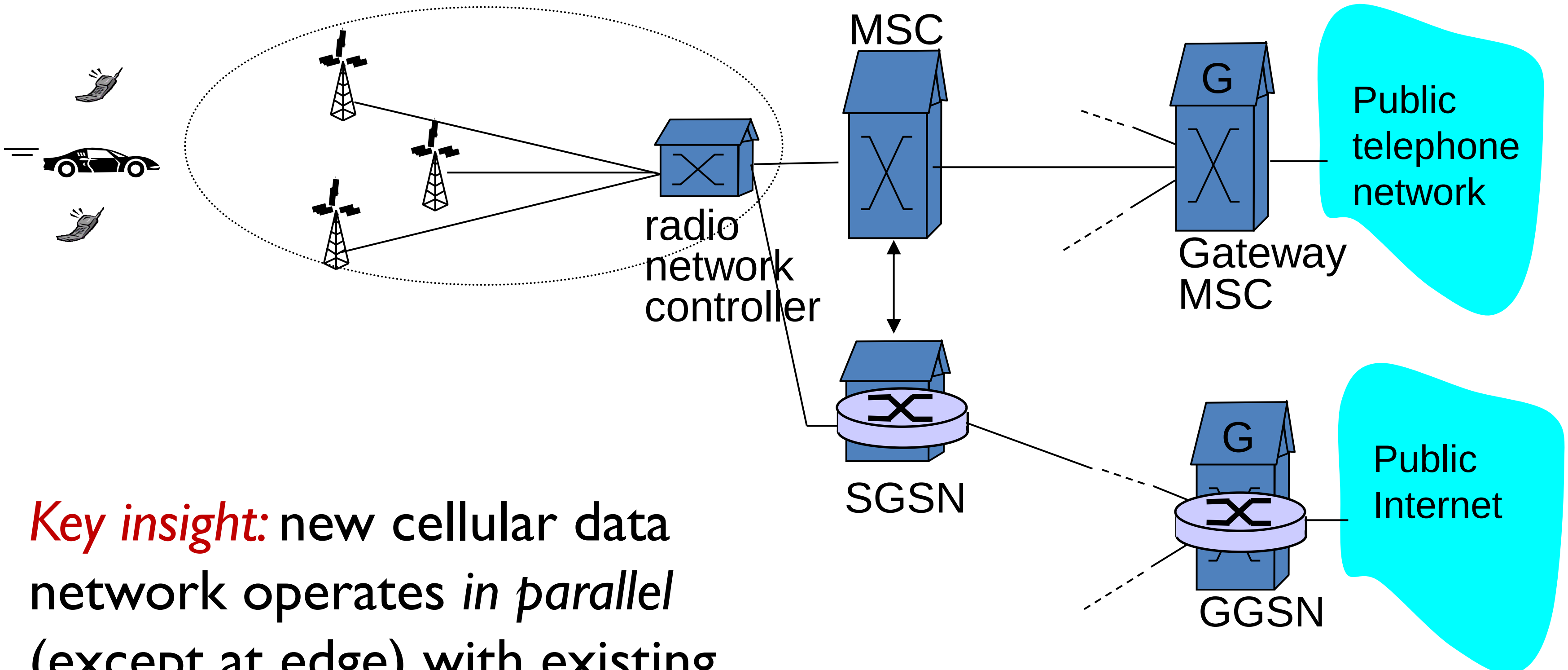
- Long Term Evolution (LTE)

5G systems: standards to be expected by 2018

- Project METIS, cf. www.metis2020.com *[mainly European initiative]*

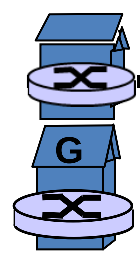
… more (and more interesting) cellular topics due to mobility (stay tuned for details)

3G (voice+data) network architecture



Key insight: new cellular data network operates *in parallel* (except at edge) with existing cellular voice network

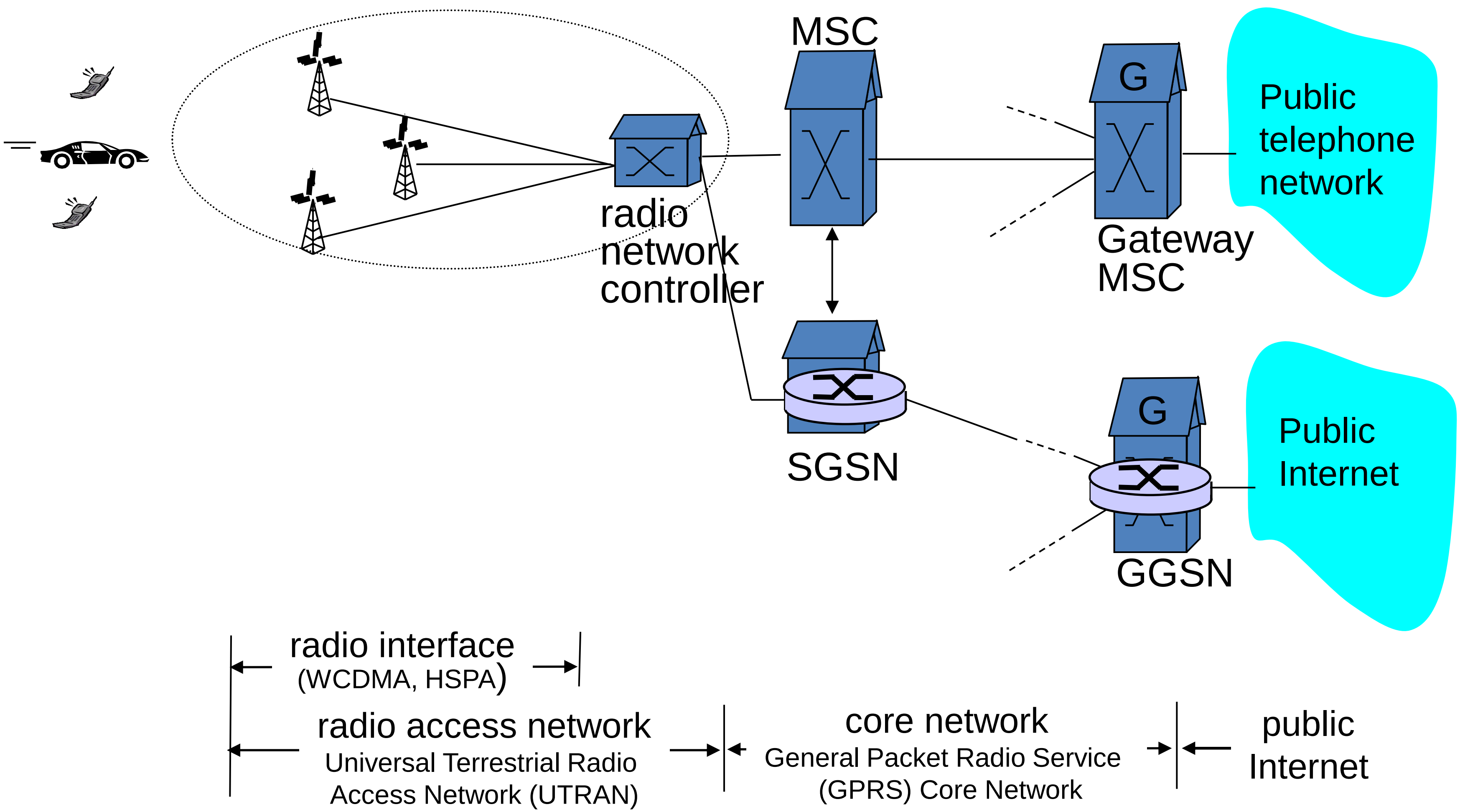
- voice network unchanged in core
- data network operates in parallel



Serving GPRS Support Node (SGSN)

Gateway GPRS Support Node (GGSN)

3G (voice+data) network architecture



Part A "Wireless and Mobile Networks"

A1. **Some Basics of Mobile Networks**

A2. **Wireless Local Networks**

A3. **Cellular Networks and Mobile Internet Access**

A4. **Mobility Management and Mobile IP**
- A4.1 Mobility Management: Principles
  - – A4.1a Addressing
  - – A4.1b Routing to a Mobile Node
- A4.2 Mobile IP
- A4.3 Managing Mobility in Cellular Networks
  - – A4.3a Routing Calls to a Mobile User
  - – A4.3b Handoffs in GSM
- A4.4 Wireless and Mobility: Impact on Higher-Layer Protocols

A5. **Satellite Communications**

A6. **Sensor Networks**

A4. Mobility Management and Mobile IP

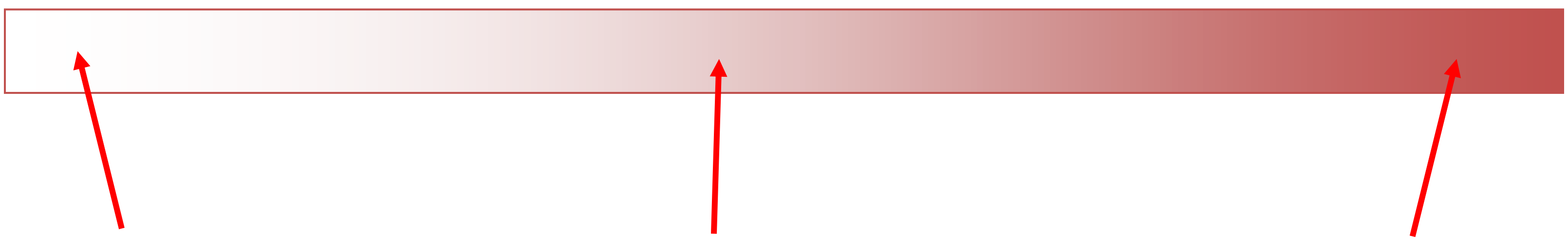
A4.1 Mobility Management: Principles

What is mobility?

- spectrum of mobility, from the *network* perspective:

no mobility

high mobility



mobile wireless user, using same access point

mobile user, connecting/ disconnecting from network using DHCP

mobile user, passing through multiple access points while maintaining ongoing connections (like cell phone)

DHCP: Dynamic Host Configuration Protocol

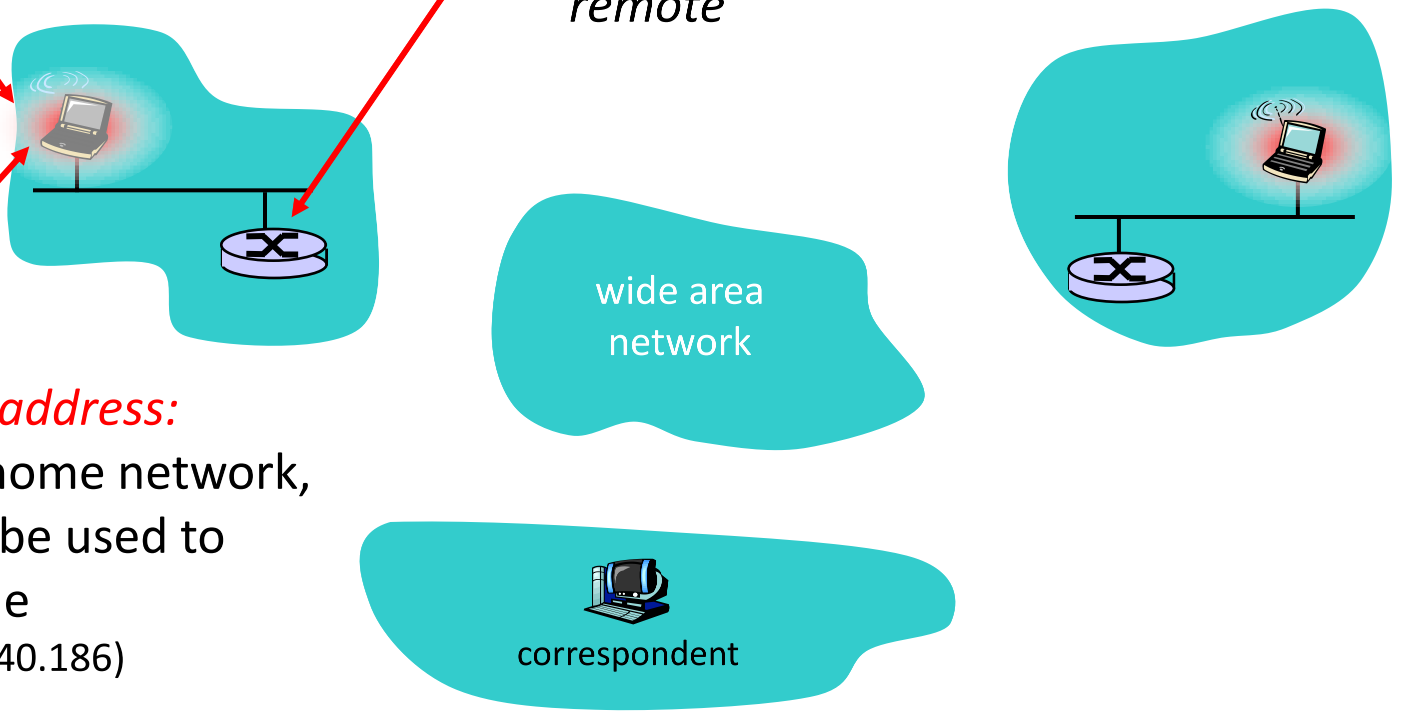
A4.1a Addressing

Mobility: Vocabulary

home network: permanent "home" of mobile
(e.g., 128.119.40/24)

home agent: entity that will perform mobility functions on behalf of mobile, when mobile is remote

Permanent address:
address in home network, *can always* be used to reach mobile
(e.g., 128.119.40.186)

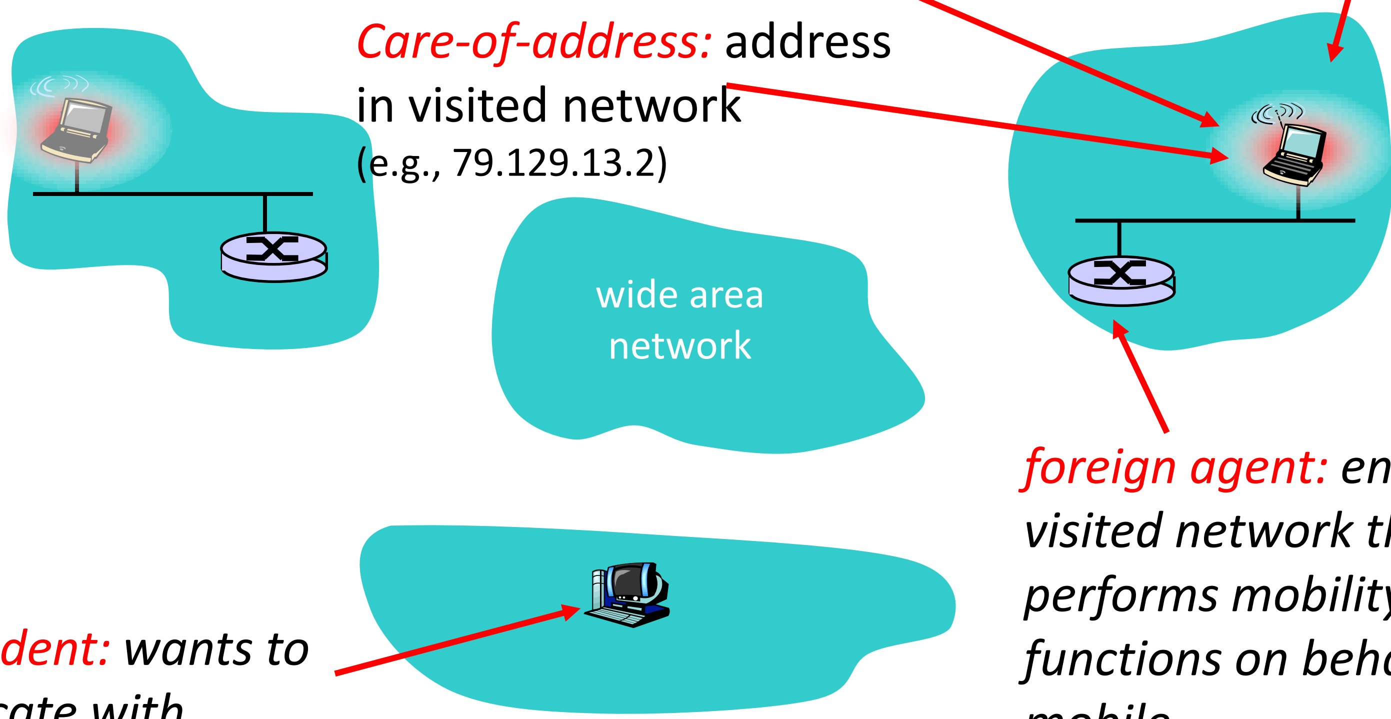


Mobility: more vocabulary

Permanent address: remains constant (e.g., 128.119.40.186)

visited network: network in which mobile currently resides (e.g., 79.129.13/24)

Care-of-address: address in visited network (e.g., 79.129.13.2)



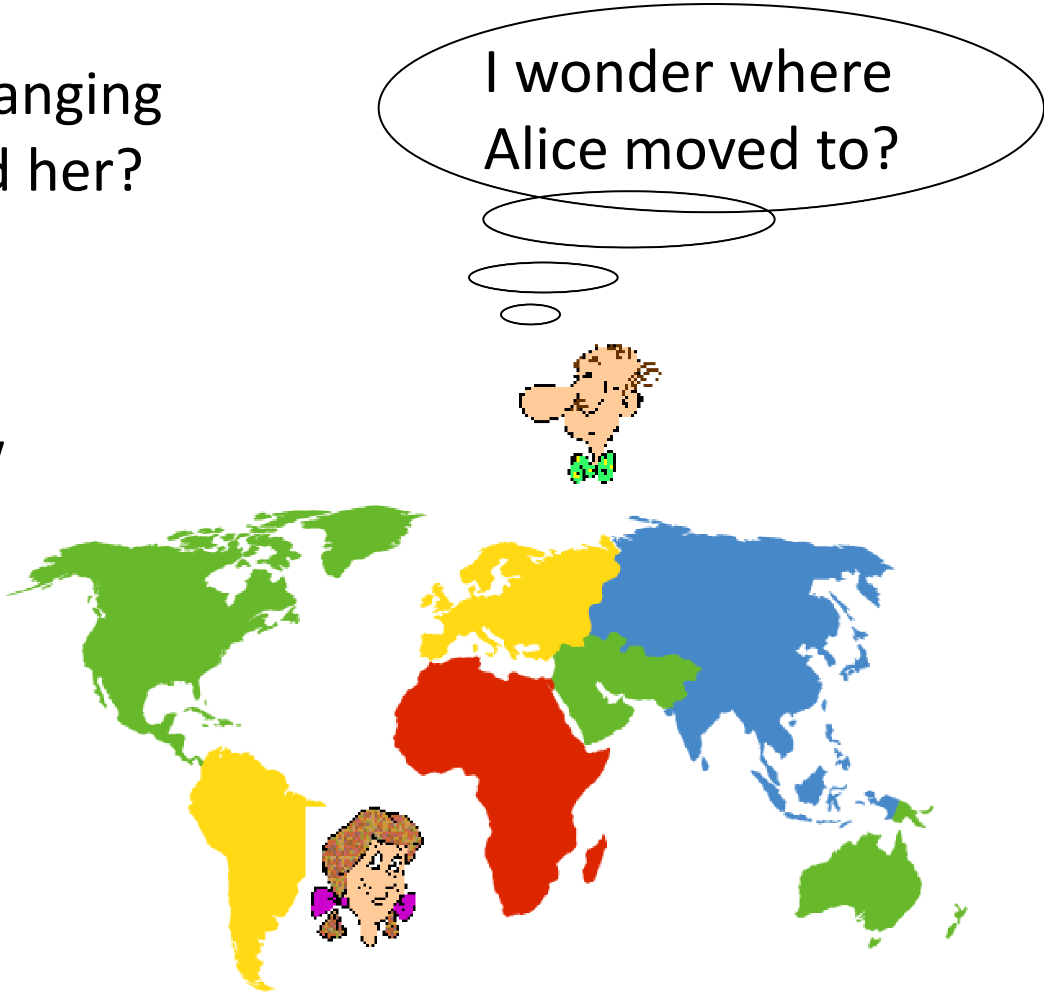
correspondent: wants to communicate with mobile

foreign agent: entity in visited network that performs mobility functions on behalf of mobile

How do *you* contact a mobile friend:

Consider friend frequently changing addresses, how do you find her?

- search all phone books?
- call her parents?
- expect her to let you know where he/she is?



A4.1b Routing to a Mobile Node

Mobility: approaches

- *Let routing handle it:* routers advertise permanent address of mobile-nodes-in-residence via usual routing table exchange
  - routing tables indicate where each mobile located
  - no changes to end-systems.
- *Let end-systems handle it:*
  - *indirect routing:* communication from correspondent to mobile goes through home agent, then forwarded to remote
  - *direct routing:* correspondent gets foreign address of mobile, sends directly to mobile.

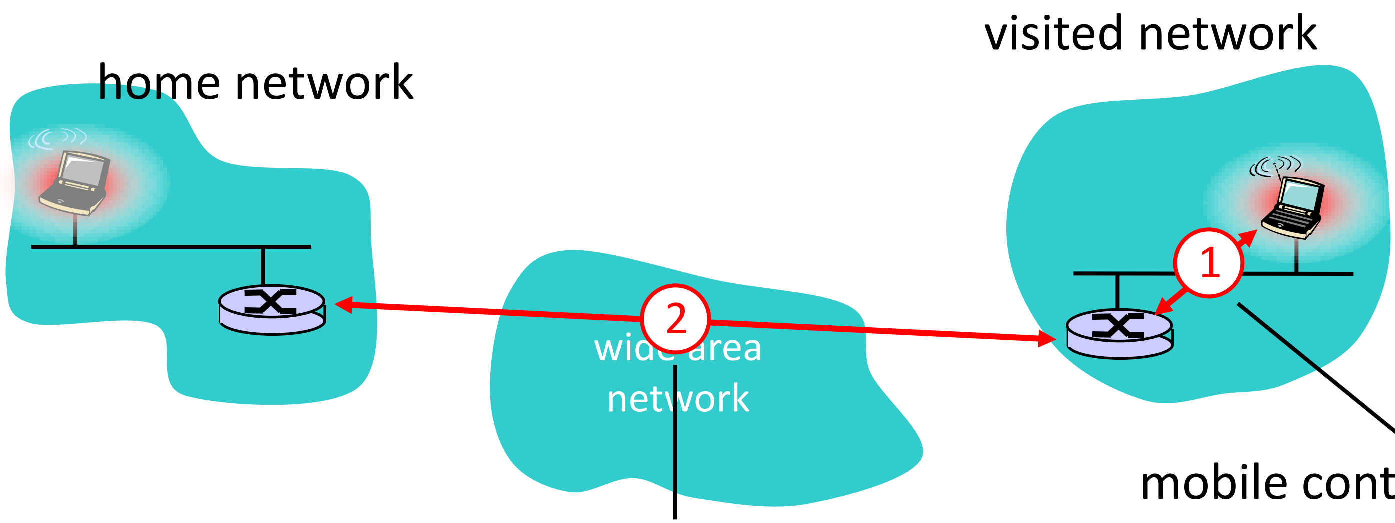
Mobility: approaches

- *Let routing handle it:* r… …ertise permanent address of mobile-nodes-in-res… …l routing table exchange
  – routing table… …re each mobile located
  – no changes to … …s.

not scalable to millions of mobiles

- *let end-systems handle it:*
  – *indirect routing:* communication from correspondent to mobile goes through home agent, then forwarded to remote
  – *direct routing:* correspondent gets foreign address of mobile, sends directly to mobile.

Mobility: registration



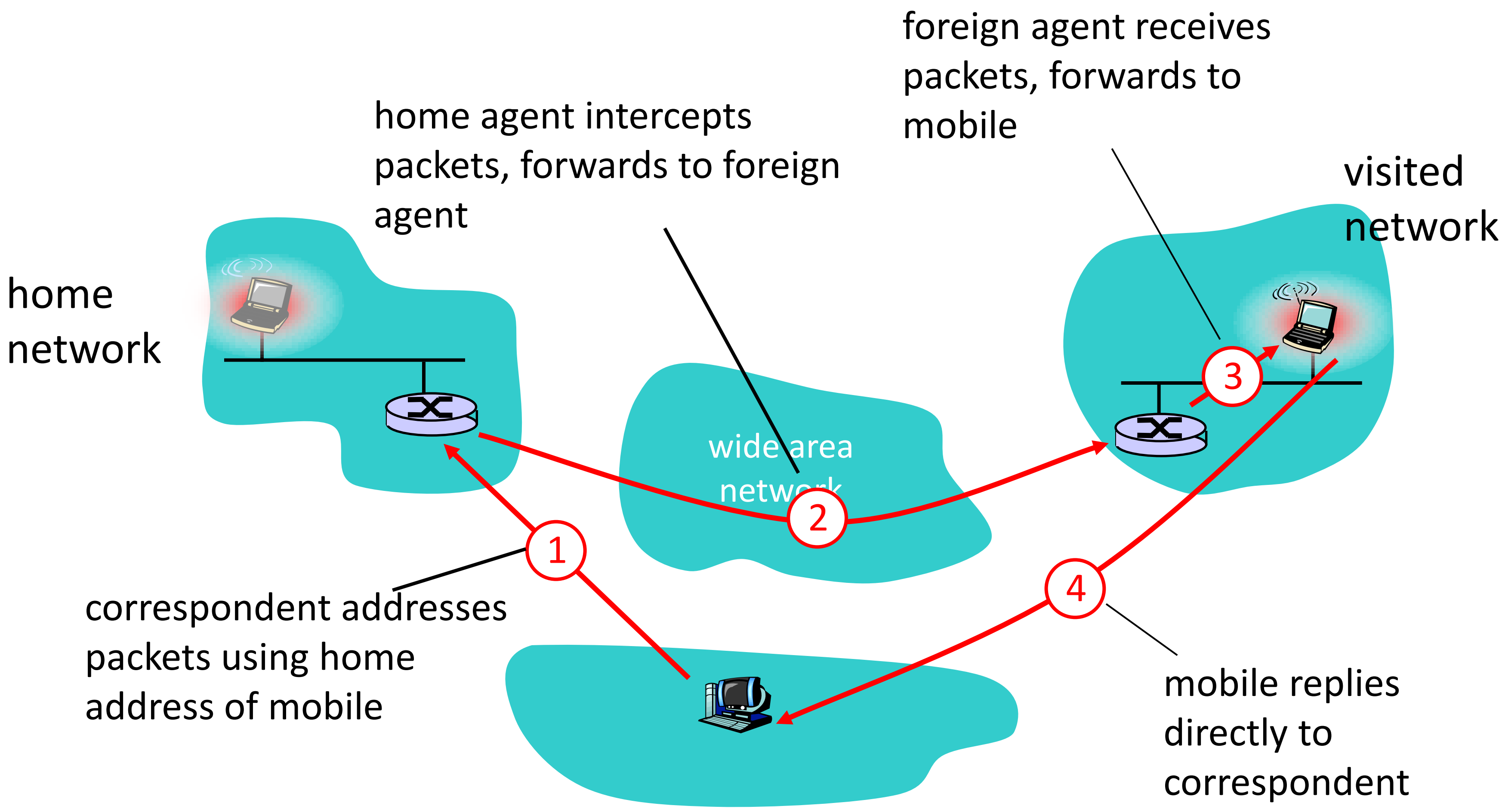
foreign agent contacts home agent in home network: "this mobile is resident in my network"

mobile contacts foreign agent on entering visited network

End result:

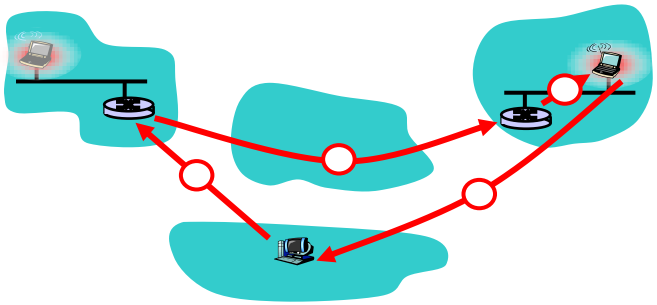
- Foreign agent knows about mobile
- Home agent knows location of mobile

Mobility via Indirect Routing



Indirect Routing: comments

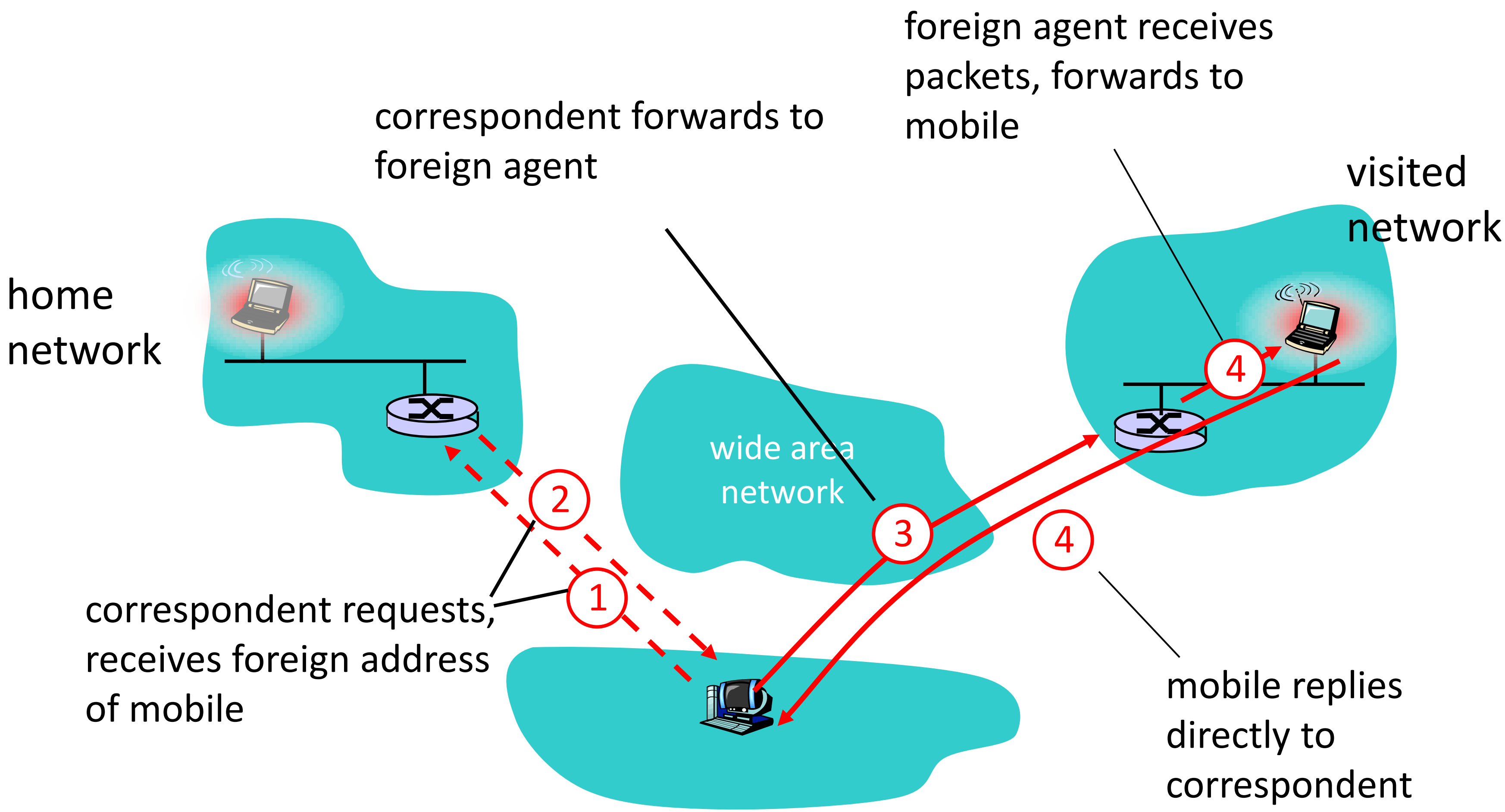
- Mobile uses two addresses:
  - permanent address: used by correspondent (hence mobile location is *transparent* to correspondent)
  - care-of-address: used by home agent to forward datagrams to mobile
- foreign agent functions may be done by mobile itself
- triangle routing: correspondent-home-network-mobile
  - inefficient when correspondent, mobile are in same network



Indirect Routing: moving between networks

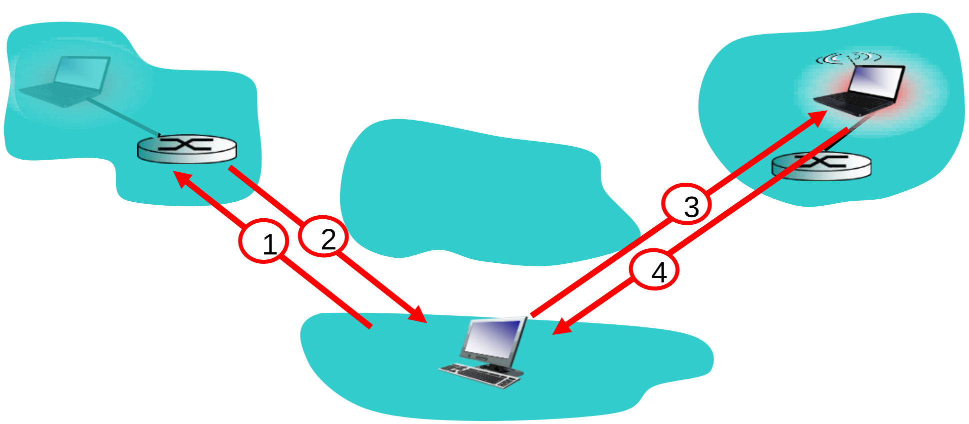
- suppose mobile user moves to another network
  - registers with new foreign agent
  - new foreign agent registers with home agent
  - home agent updates care-of-address for mobile
  - packets continue to be forwarded to mobile (but with new care-of-address)
- mobility, changing foreign networks transparent: *ongoing connections can be maintained!*

Mobility via Direct Routing



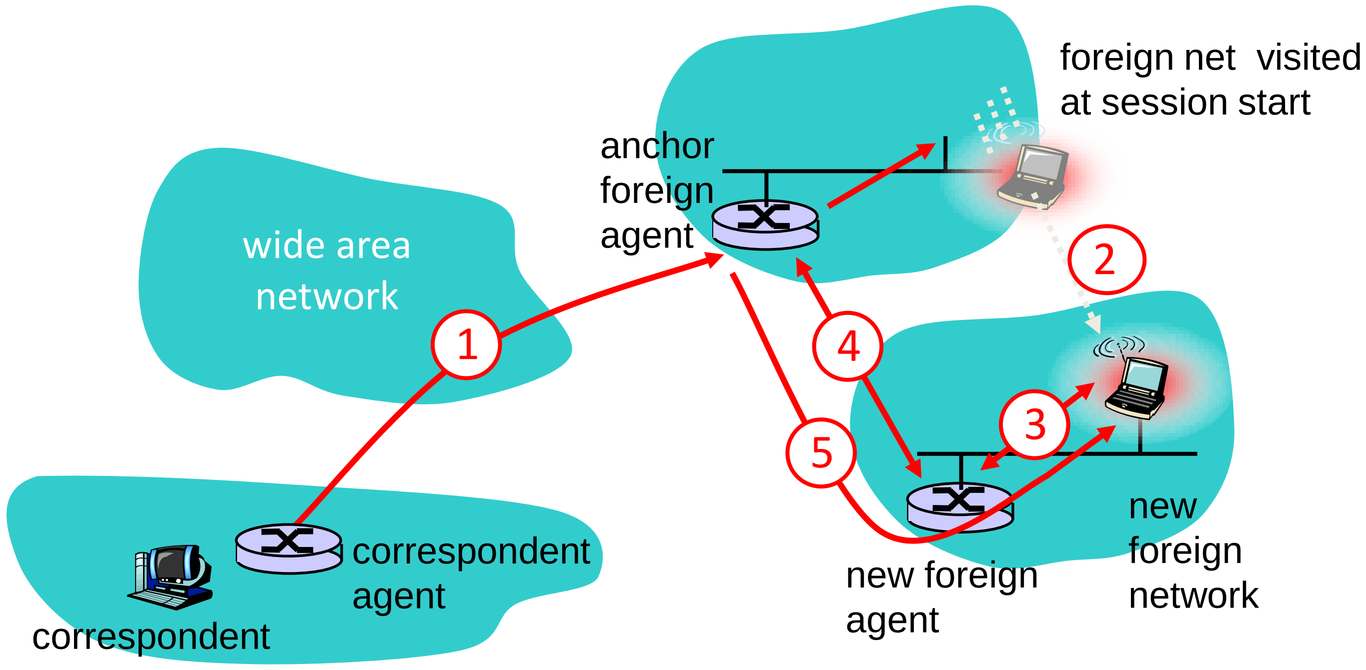
Mobility via Direct Routing: comments

- overcome triangle routing problem
- non-transparent to correspondent: correspondent must get care-of-address from home agent
  - what if mobile changes visited network?



Accommodating mobility with direct routing

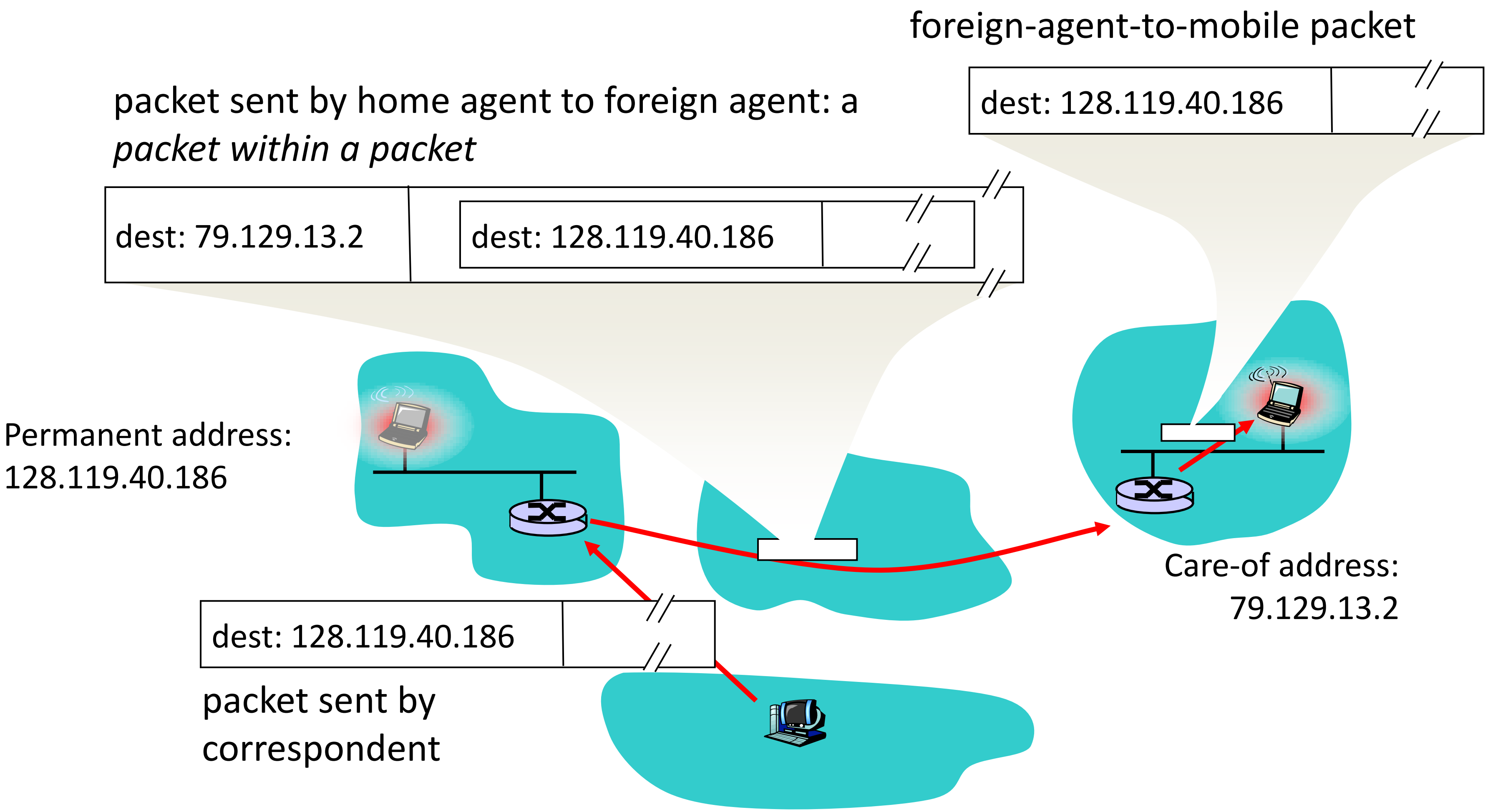
- anchor foreign agent: FA in first visited network
- data always routed first to anchor FA
- when mobile moves: new FA arranges to have data forwarded from old FA (chaining)



A4.2 Mobile IP

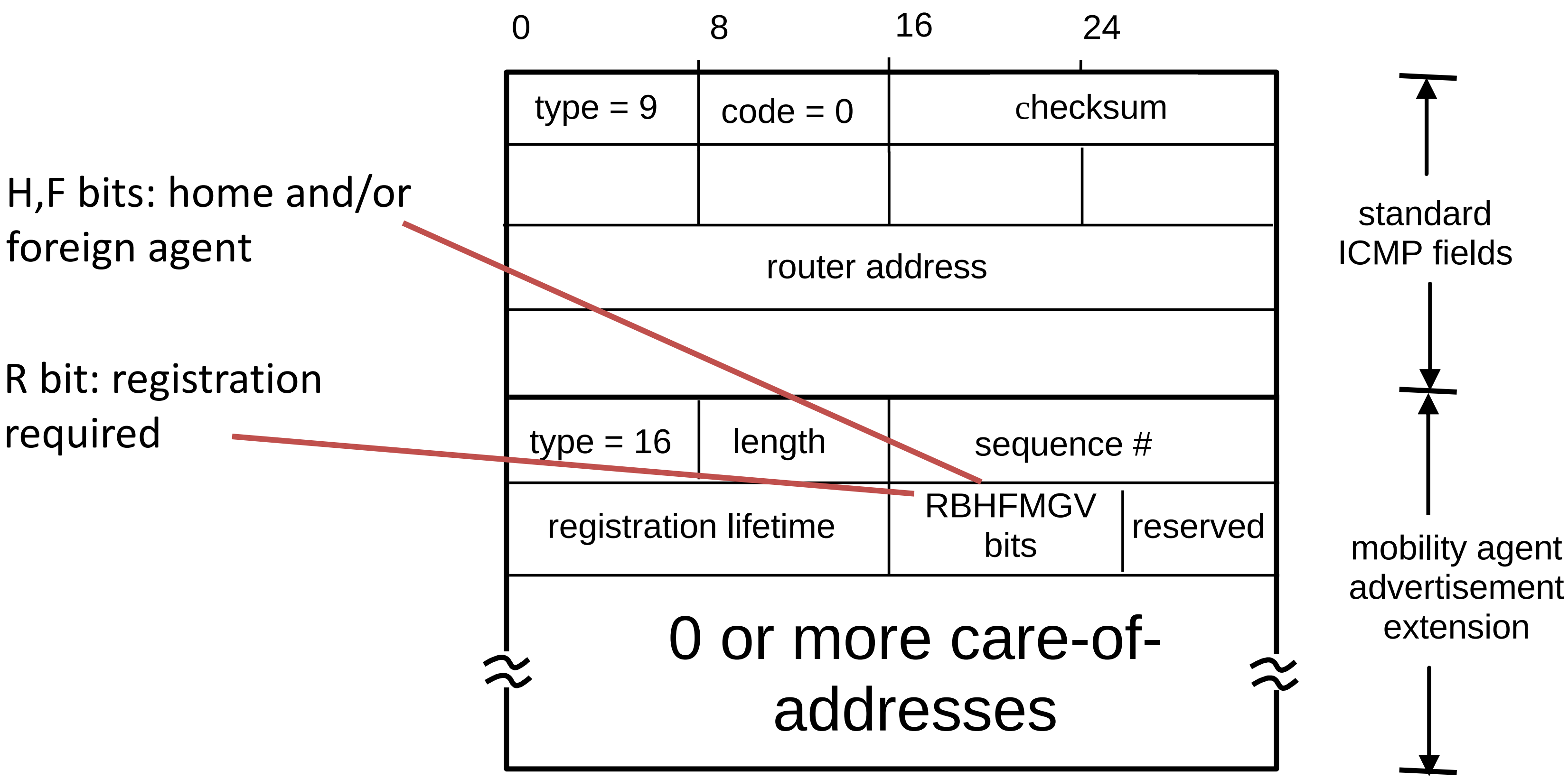
- RFC 3344
- has many features we've seen:
  - home agents, foreign agents, foreign-agent registration, care-of-addresses, encapsulation (packet-within-a-packet)
- three components to standard:
  - indirect routing of datagrams
  - agent discovery
  - registration with home agent

Mobile IP: indirect routing

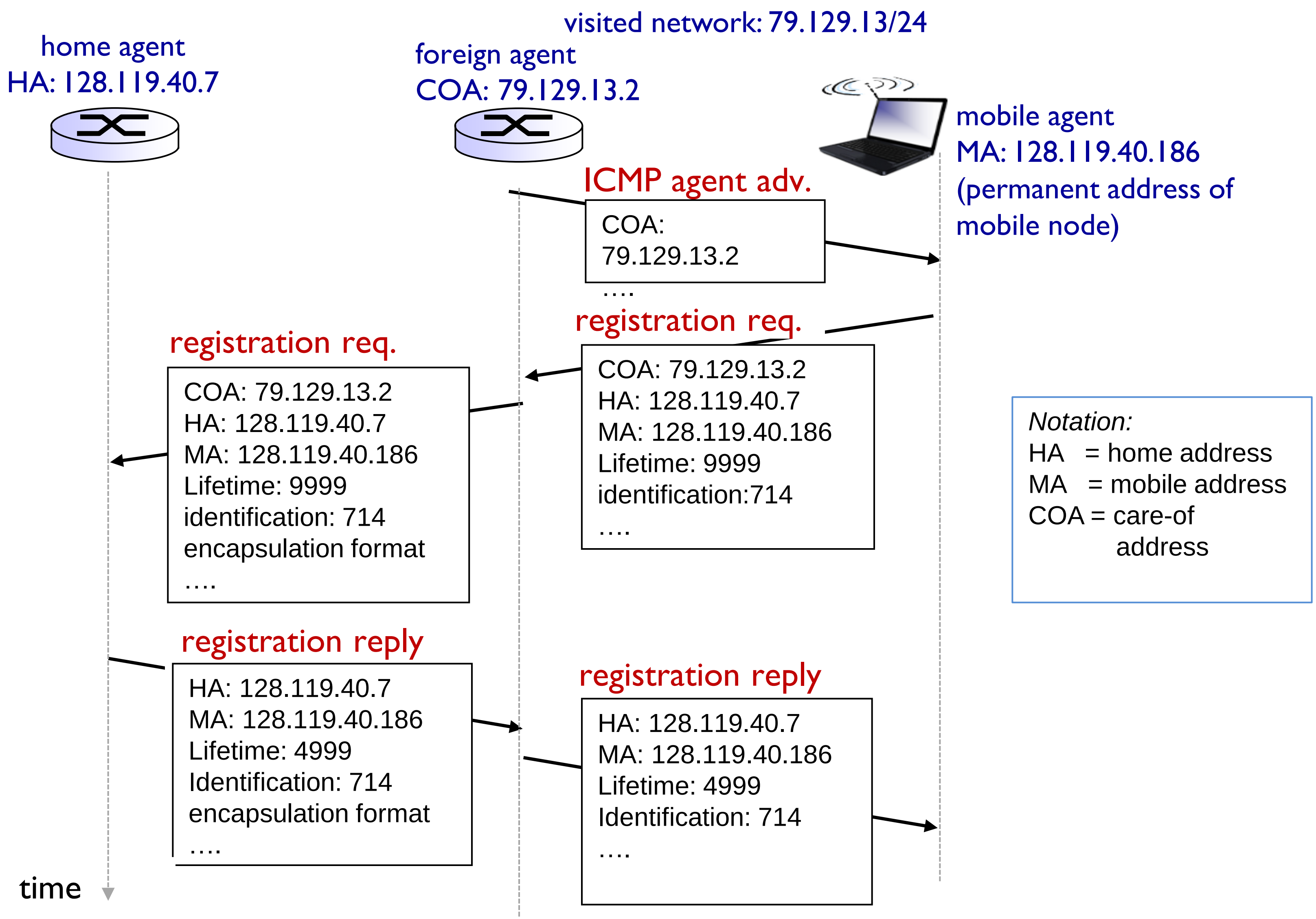


Mobile IP: agent discovery

- agent advertisement: foreign/home agents advertise service by broadcasting ICMP messages (type-field = 9)



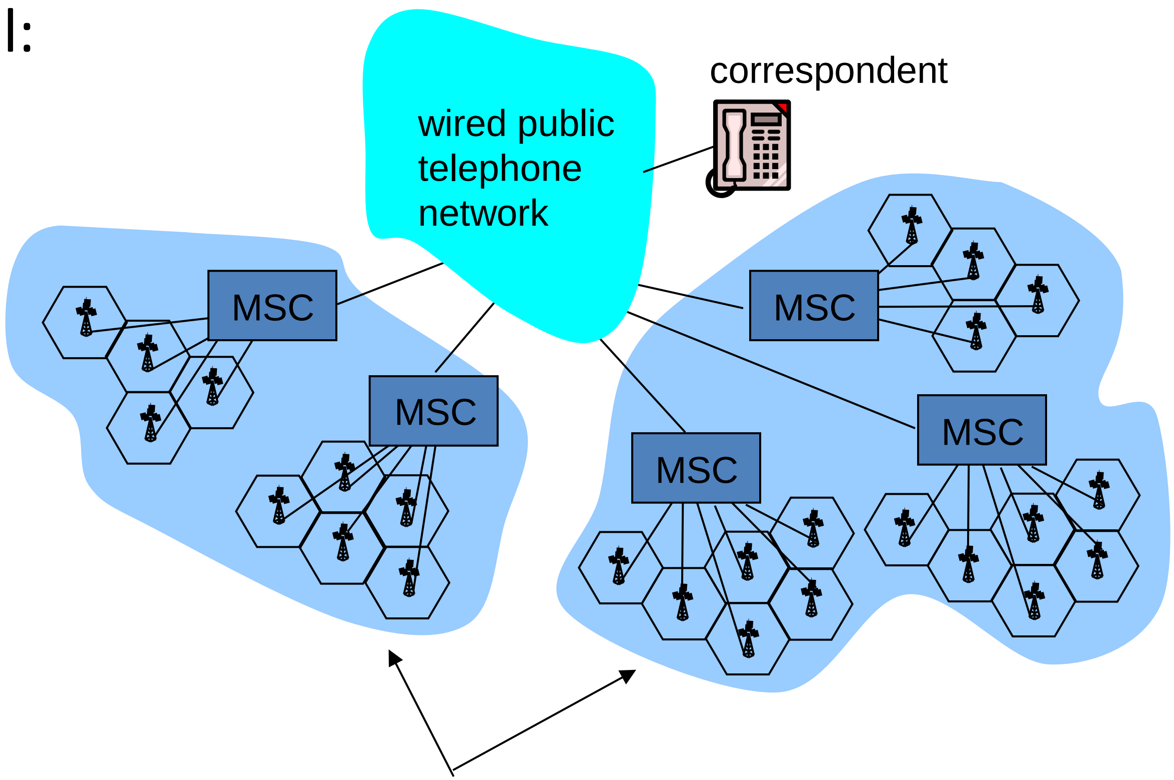
Mobile IP: registration example



A4.3 Managing Mobility in Cellular Networks

Components of cellular network architecture

recall:



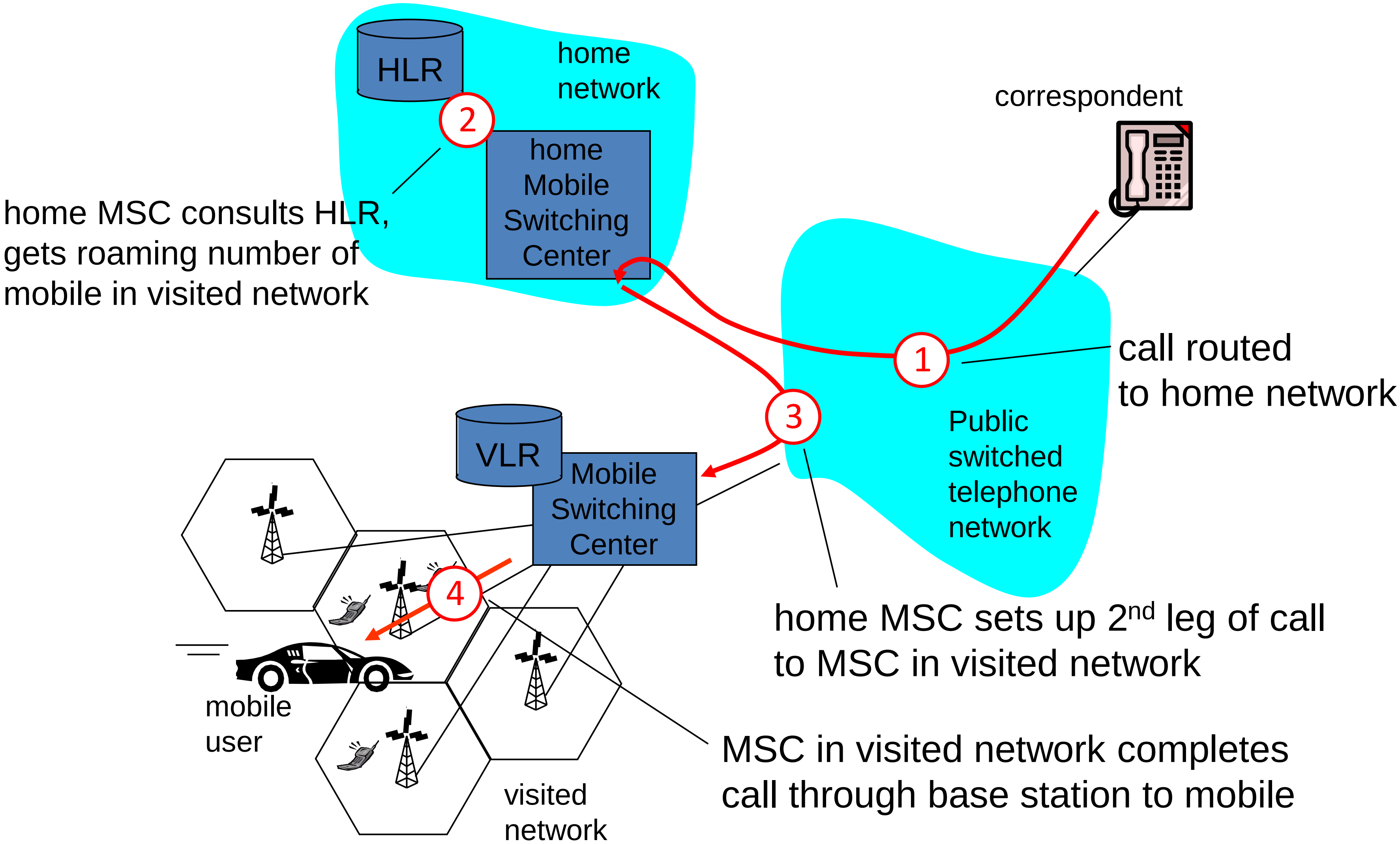
different cellular networks,
operated by different providers

Handling mobility in cellular networks

- *home network:* network of cellular provider you subscribe to (e.g., Sprint PCS, Verizon)
  - *home location register (HLR):* database in home network containing permanent cell phone #, profile information (services, preferences, billing), information about current location (could be in another network)
- *visited network:* network in which mobile currently resides
  - *visitor location register (VLR):* database with entry for each user currently in network
  - could be home network

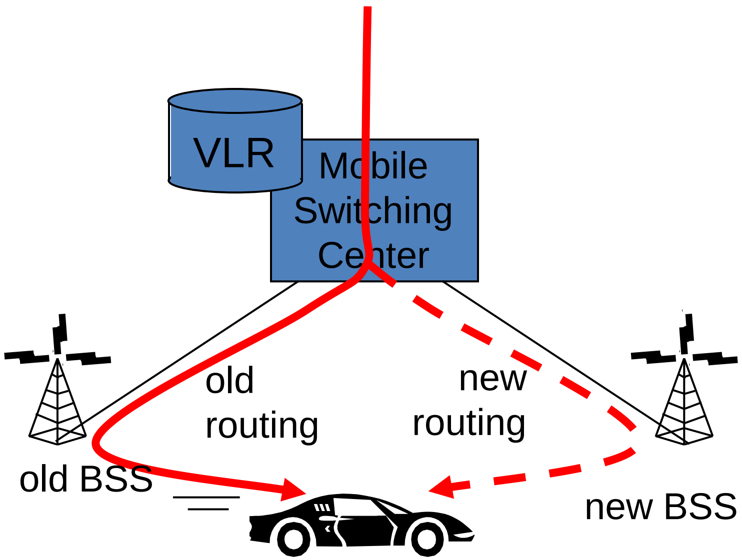
A4.3a Routing Calls to a Mobile User

GSM: indirect routing to mobile



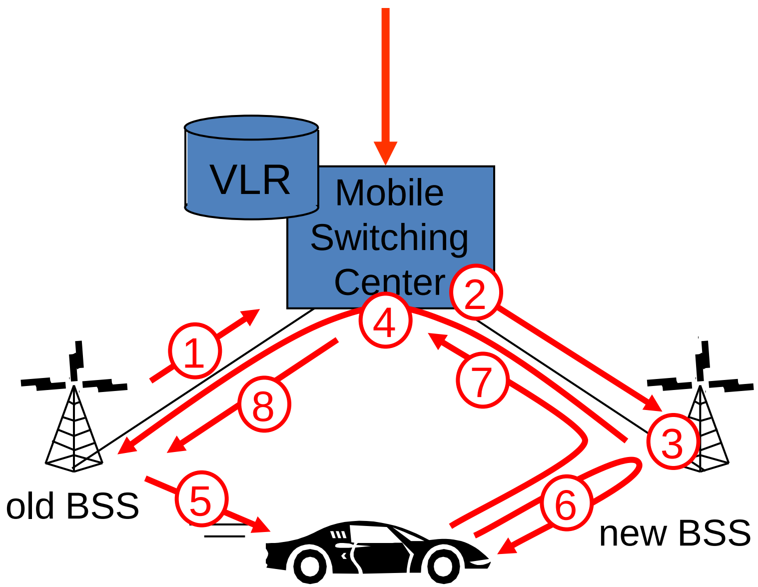
A4.3b Handoffs in GSM

GSM: handoff with common MSC



- Handoff goal: route call via new base station (without interruption)
- reasons for handoff:
  - stronger signal to/from new BSS (continuing connectivity, less battery drain)
  - load balance: free up channel in current BSS
  - GSM doesn't mandate why to perform handoff (policy), only how (mechanism)
- handoff initiated by old BSS

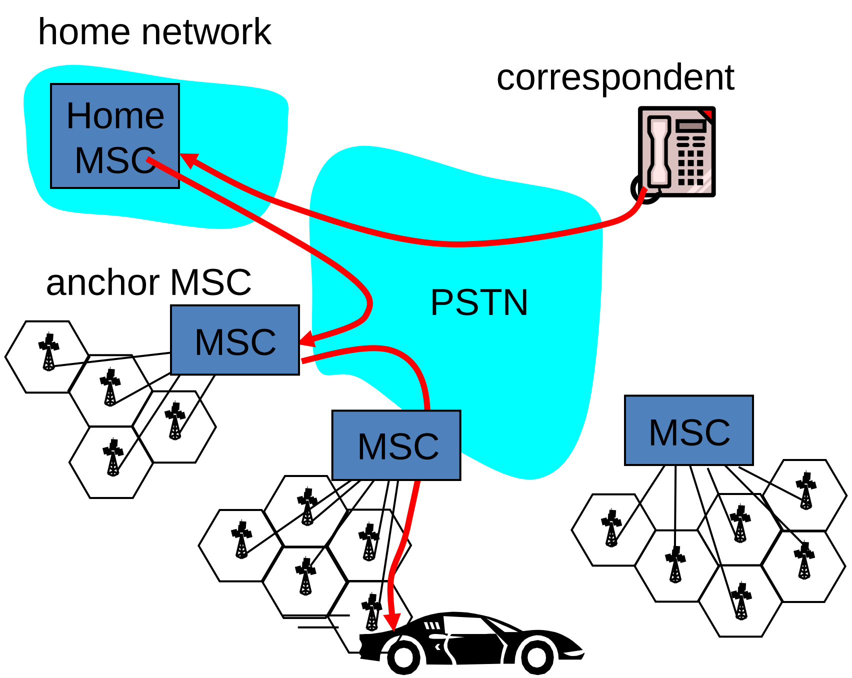
GSM: handoff with common MSC



1. old BSS informs MSC of impending handoff, provides list of 1^+ new BSSs
2. MSC sets up path (allocates resources) to new BSS
3. new BSS allocates radio channel for use by mobile
4. new BSS signals MSC, old BSS: ready
5. old BSS tells mobile: perform handoff to new BSS
6. mobile, new BSS signal to activate new channel
7. mobile signals via new BSS to MSC: handoff complete. MSC reroutes call

8 MSC-old-BSS resources released

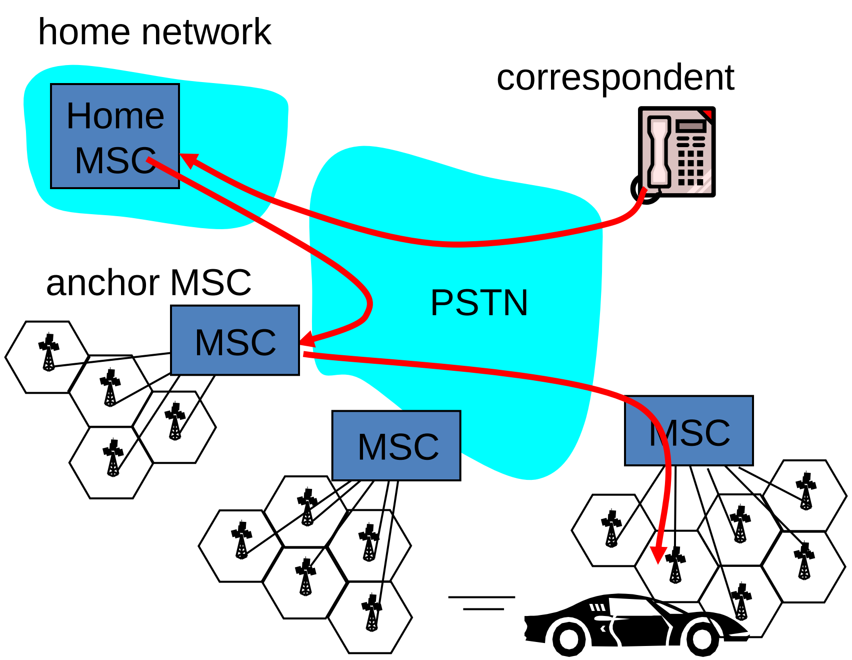
GSM: handoff between MSCs



(a) before handoff

- *anchor MSC:* first MSC visited during call
  - call remains routed through anchor MSC
- new MSCs add on to end of MSC chain as mobile moves to new MSC
- IS-41 allows optional path minimization step to shorten multi-MSC chain

GSM: handoff between MSCs



(b) after handoff

- *anchor MSC:* first MSC visited during call
  - call remains routed through anchor MSC
- new MSCs add on to end of MSC chain as mobile moves to new MSC
- IS-41 allows optional path minimization step to shorten multi-MSC chain

Mobility: GSM versus Mobile IP

GSM element	Comment on GSM element	Mobile IP element
Home System	Network to which mobile user's permanent phone number belongs	Home Network
Gateway Mobile Switching Center, or "home MSC". Home Location Register (HLR)	Home MSC: point of contact to obtain routable address of mobile user. HLR: database in home system containing permanent phone number, profile information, current location of mobile user, subscription information	Home Agent
Visited System	Network other than home system where mobile user is currently residing	Visited Network
Visited Mobile services Switching Center. Visitor Location Register (VLR)	Visited MSC: responsible for setting up calls to/from mobile nodes in cells associated with MSC. VLR: temporary database entry in visited system, containing subscription information for each visiting mobile user	Foreign Agent
Mobile Station Roaming Number (MSRN), or "roaming number"	Routable address for telephone call segment between home MSC and visited MSC, visible to neither the mobile nor the correspondent.	Care-of-Address

A4.4 Wireless and Mobility: Impact on Higher Layer Protocols

- logically, impact *should* be minimal …
  - best effort service model remains unchanged
  - TCP and UDP can (and do) run over wireless, mobile

- … but performance-wise:
  - packet loss/delay due to bit-errors (discarded packets, delays for link-layer retransmissions), and handoff
  - TCP interprets loss as congestion, will decrease congestion window un-necessarily
  - delay impairments for real-time traffic
  - limited bandwidth of wireless links

Part A Summary (Chapters A1-A4)

Wireless

- wireless links:
  - capacity, distance
  - channel impairments
  - CDMA
- IEEE 802.11 (“Wi-Fi”)
  - CSMA/CA reflects wireless channel characteristics
- cellular access
  - architecture
  - standards (e.g., GSM, 3G, 4G LTE)

Mobility

- principles: addressing, routing to mobile users
  - home, visited networks
  - direct, indirect routing
  - care-of-addresses
- case studies
  - mobile IP
  - mobility in GSM
- impact on higher-layer protocols

Part A "**Wireless and Mobile Networks**"

A1. **Some Basics of Mobile Networks**

A2. **Wireless Local Networks**

A3. **Cellular Networks and Mobile Internet Access**

A4. **Mobility Management and Mobile IP**

A5. **Satellite Communications**

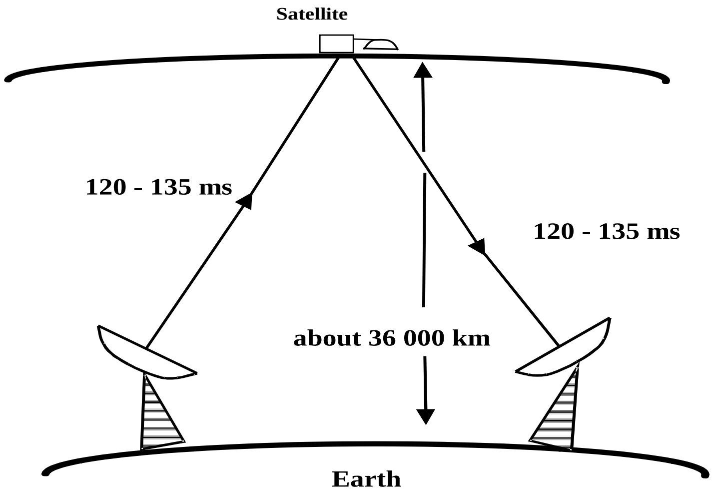
- A5.1 Data Transmission via Satellites
- A5.2 Types of Satellites (LEOs, MEOs, GEOs) and their Usage

A6. **Sensor Networks**

A5. Satellite Communications

A5.1 Data Transmission via Satellites

Data Transmission via Satellite



GEOs (**Geo**synchronous/**Geo**stationary satellites)

From Wikipedia :
http://de.wikipedia.org/wiki/Bild:Astra_2D_3A_sp.JPG#file

Data transmission via satellite (continued) :

Transformation of frequency by the satellite (by means of ***Transponder***);

$\Rightarrow$ frequencies used, e.g.: C-Band 4/6 GHz, Ku-Band 12/14 GHz

moreover : Ka-Band, e.g. 20/30 GHz or 23/26 GHz

Example: 4/6 GHz $\wedge$ Bandwidth $\leq$ 500 MHz

$\Rightarrow$ [5.925, 6.425] GHz towards the satellite;

[3.7, 4.2] GHz towards the earth-station.

Important examples of satellite systems during the past : INTELSAT Systems (e.g. INTELSAT 14 since Nov. 2009 as a TV satellite; expected life-time: 15 Years; including an ‘Internet Router In Space’ IRIS for military communication based on IP)

moreover : **LEO**s (**L**ow **E**arth **O**rbiting satellites), cf. IRIDIUM System (Motorola) et al.

Propagation of radio signals:

The wave-length is influencing

– Structure and size of antennas to be used (e.g. parabolic antennas)

– Manner of signal propagation within the atmosphere (cf. below)

Signal propagation in the atmosphere

- Speed of propagation: speed of light – NOT, e.g., speed of sound !!! ☺

  - existing layers of ionisation :

E-Layer → Ionisation of O-Molecules

F-Layer → F_1-Layer with ionisation of N - Molecules
→ F_2-Layer with ionisation of O - Atoms or H or He

D-Layer → Existent during day-time

→ Layers with decreasing distance from earth : F, E, D, i.e. D = layer closest to earth

1 $\lambda < 10$m
(cm-, dm-waves, **UKW**)

Remark: used for satellite transmissions
(because of the lack of reflections of waves in the layers D, E, and F)

2 $\lambda \sim 10$m, ..., 200m (**KW**)

Remark: proximity radiation (Nahstrahlung) resulting only up to an angle of ψ (for sending signals),
e.g. $\psi = 20°$ for $\lambda = 15$m; $\psi = 50°$ for $\lambda = 25$m
reflections of waves in the F layer

3 $\lambda \sim 200$m, ..., 2000m (**MW**, **LW**)

Remark: reflections of waves in the E layer

A5.2 Types of Satellites (LEOs, MEOs, GEOs) and their Usage

- ***Classes of communication satellites***:

  - **GEO**s (**G**eostationary **E**arth **O**rbiter) : height (distance from earth) of about 36.000 km, synchronous with rotation of earth
  - **MEO**s (**M**edium **E**arth **O**rbiter) : height of about 10.000 – 15.000 km
  - **LEO**s (**L**ow **E**arth **O**rbiter) : height of about 700 – 1.500 km

In between: about 2.000-6.000 km $\rightarrow$ inner **Van-Allen-(radiation) belt** ;

about 15.000-30.000 km $\rightarrow$ outer **Van-Allen-(radiation) belt**

[with a high concentration of ionisized/ionized (energetic charged) particles]

Classes of Satellites (LEOs, MEOs, GEOs)

- **Examples of satellite communication systems** with
  - ***GEOs***:

    Inmarsat (**IN**ternational **MAR**itime **SAT**ellite Organisation)

    since 1982
    $\rightarrow$ 9 geostationary/geosynchronous satellites covering the complete surface of the earth (besides polar regions);

    frequencies used : [1.5, 1.6] GHz; communication with mobile stations MS (e.g. MS on ships, in air planes); early data rates : 1.2 up to 64 kb/s;

    Currently: ***Inmarsat IV*** for Broadband (!) Internet Access ($\rightarrow$ 492 kbit/s, expected life-time : $\approx$ 13 Years)

Inmarsat – areas of application, among others :

- Communication for ships, e.g. traveling on an ocean
- Voice-/fax-/data transmissions from/to air-planes
- Emergency calls (e.g. during expeditions)
- Telefax
- Control of vehicle fleets (*Fahrzeugflotten*), ...

Examples of satellite communication systems (*continued*) using

- ***MEOs* :** **GPS** (**G**lobal **P**ositioning **S**ystem)
  → 24 satellites in height of about 18.000 km : for each point of the earth's surface access to ≥ 3 satellites (in general 5-9 satellites);
  exact determination of position for MS (namely the GPS-receivers, e.g. vehicles) based on the propagation delays of the time signals sent by the satellites;
  Accuracy of the position determined : a few meters

- ***LEOs* :** c.f. "**Iridium-Flop**" with a duration of operation of just 1998-3/2000; usage of 66 LEO satellites to establish the data transmission MS ↔ MS.

Where to place GEO Satellites?

... **above equator**

... but **at what distance ?**

- *Gravitational force/pull* ("Anziehungskraft") of the earth onto the satellite:

$$\mathbf{F_g = m \cdot g \cdot (R/r)^2}$$

- *Centrifugal force* ("Fliehkraft") onto the satellite:

$$\mathbf{F_z = m \cdot r \cdot \omega^2 = m \cdot r \cdot (2\pi f)^2}$$

where

m = mass of the satellite

R = radius of earth, i.e. R = 6370 km

r = distance between satellite and center of earth

g = acceleration of gravity ('Erdbeschleunigung'), i.e. g = 9,81 m/s^2

f = 1/T, where T = round trip time of satellite, f = rotation frequency

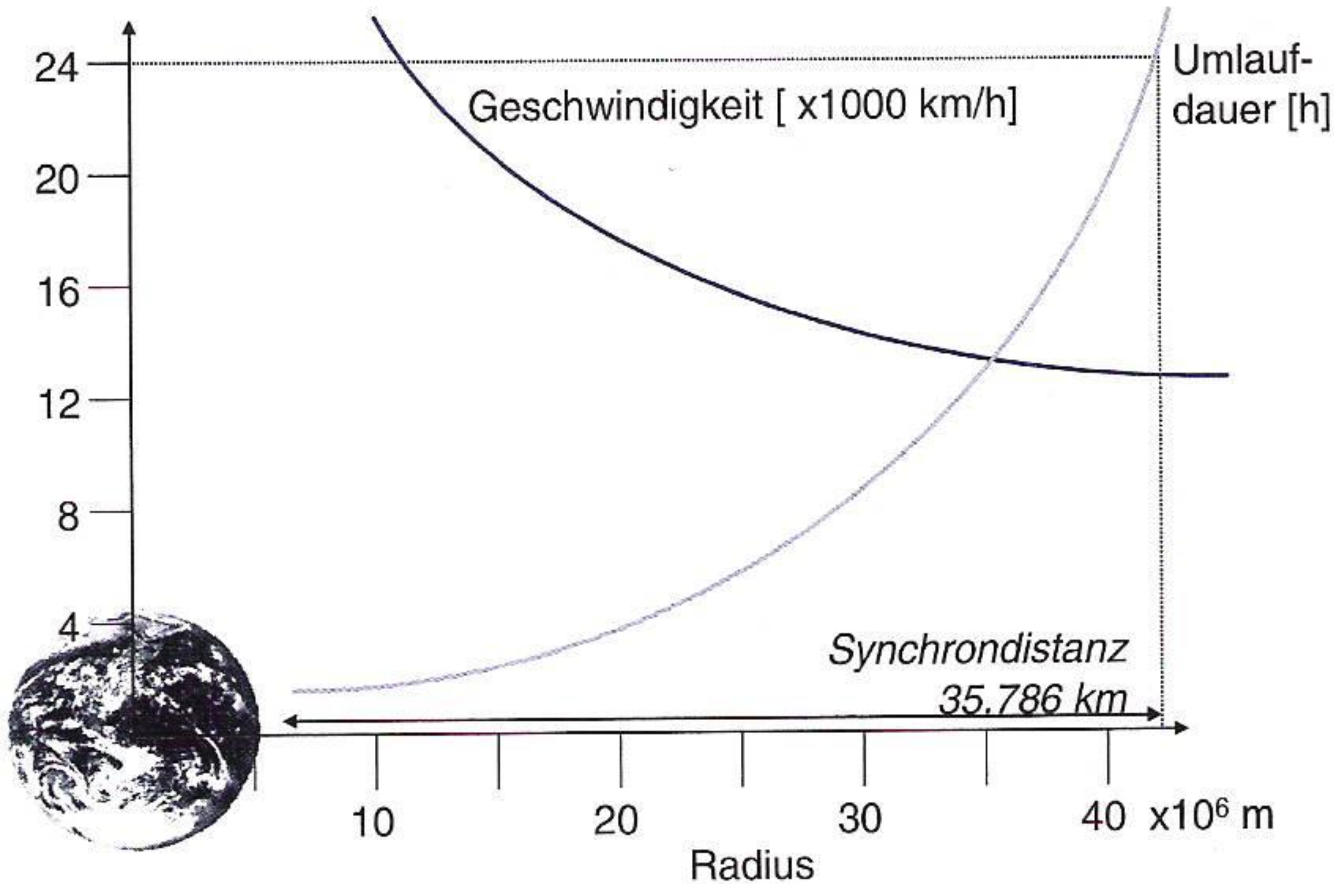
Now, $F_g = F_z$ implies:

$$g \bullet (R/r)^2 = r \bullet \omega^2 \Leftrightarrow \frac{g \bullet R^2}{\omega^2} = r^3$$

$$\text{and therefore} : r = \sqrt[3]{g \bullet R^2 /(2 \bullet \pi \bullet f)^2}$$

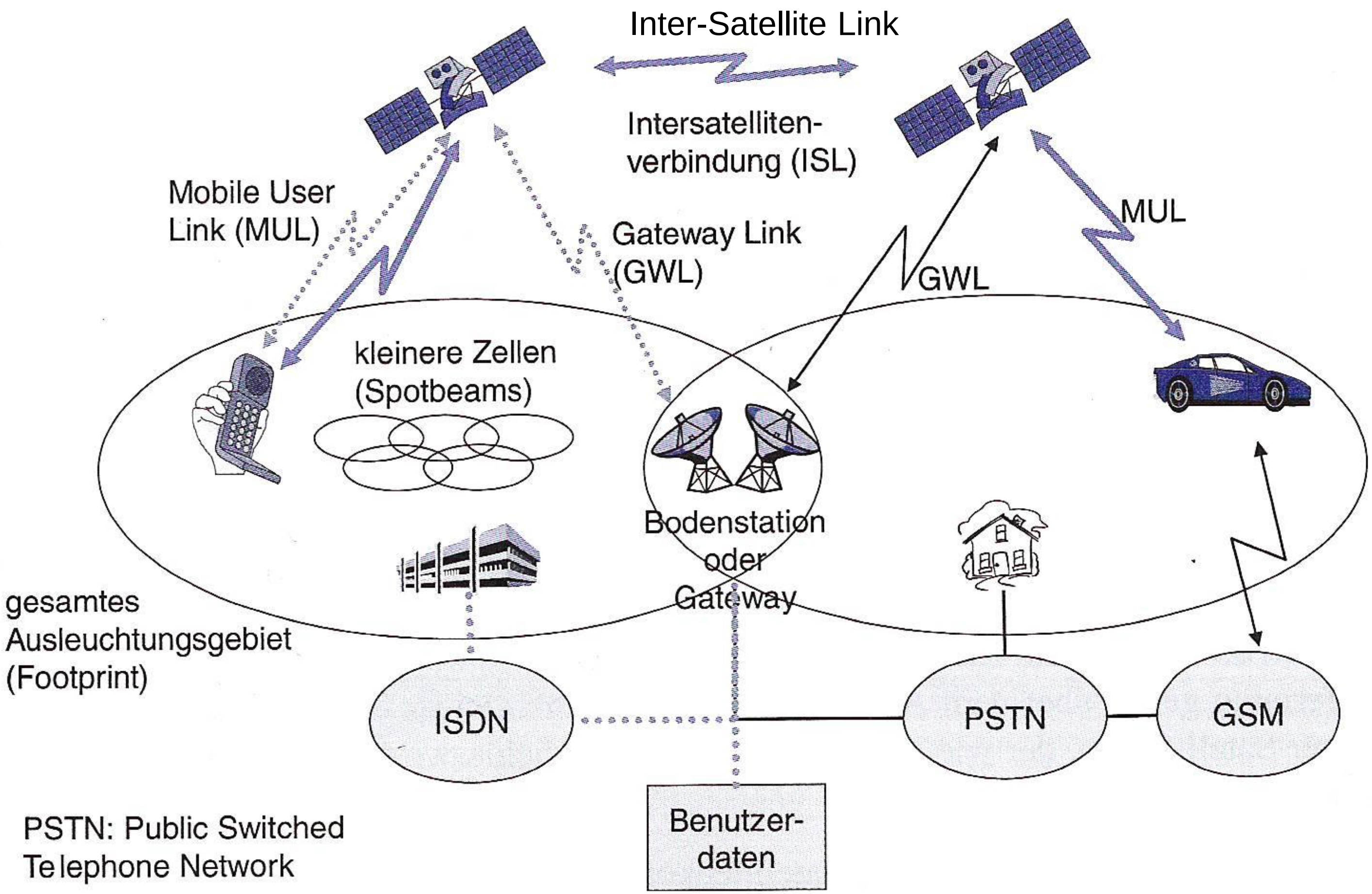
For T = 24 h (i.e. 1 day), this yields **r* = 35 786 km,** where r* = r – R (i.e. r* = distance between satellite and surface of earth).

Dependency between Round Trip Time of a Satellite and its Distance from Earth



(from: [Schiller "Mobilkommunikation", 2003])

Typical Satellite System for World-wide Mobile Communications



(from: [Schiller "Mobilkommunikation", 2003])

Part A “Wireless and Mobile Networks”

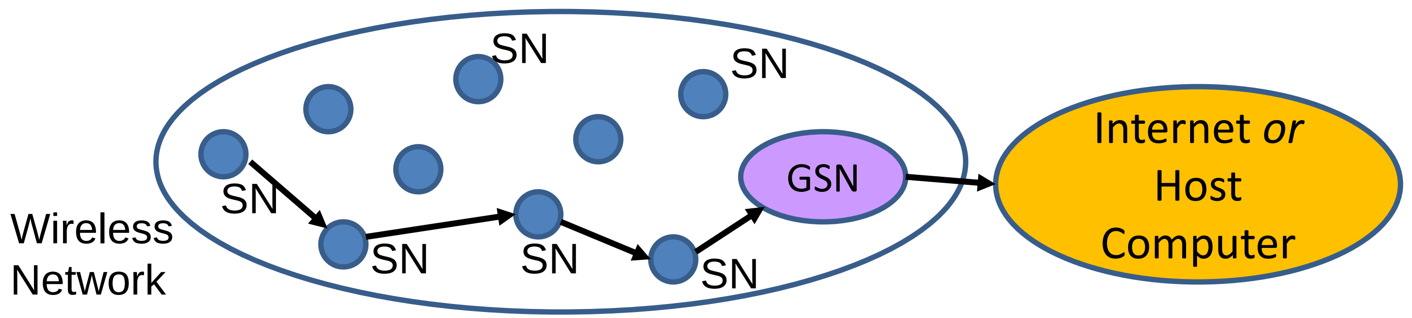
A6. Sensor Networks

A6.1 Applications of Sensor Networks

Wireless Sensor Networks (WSN):

- Spatially distributed autonomous sensors (cooperatively monitoring physical or environmental conditions)
- Sensors embedded into sensor nodes SN together with a radio transceiver, a small microcontroller and an energy source (typically a battery)
- (Multihop) Wireless network used to interconnect the sensor nodes and a Gateway Sensor Node GSN (providing access to the Internet and/or a computation infrastucture).

Typical **WSN Architecture**:



Wireless Sensor Networks – Some Challenges

- typically large number of nodes
- cheap nodes with low transmission & computation capacity
- boundary conditions exist (e.g. highly dynamic topology) leading to very difficult routing problems
- unattended operation
- heterogeneous nodes
- (potentially very serious) security problems to be solved

Wireless Sensor Networks – Classes of Applications

- Military (first important class existing and researched ! → currently still with biggest financial support, in particular in the US)
- Environmental Observation and Forecasting Systems (EOFS) 1
- Habitat Monitoring
- Traffic Control and Driver Assistance
- Health
- Machine Health Monitoring 2
- Industrial Process Monitoring and Control 3
- Home Automation

etc, etc.

→ cf. also :
extremely strong tendency towards **"Internet of Things"**

Source of Figs.: National Instruments (NI) Tutorial of July 23, 2009

Applications of Sensor Networks : Examples I

→ cf., e.g., : N. Xu "A Survey of Sensor Network Applications", Survey Paper for CS694a, Computer Science Dept., University of Southern California (2003)

- **Habitat monitoring applications**
  - **Great Duck Island** (**GDI**) system → monitor behavior of storm petrel (Bereich 'Nachhaltigkeit')
  - **Remote Ecological Micro-Sensor Network** (**PODS** system)
    - Investigate why endangered species of plants will grow in one area but not in neighboring areas (in Hawaii Volcanos National Park)
    - Camouflaged sensor nodes (called *Pods*) are deployed; *Pods* consist of a computer, a radio transceiver (Bluetooth or IEEE 802.11b) and environmental sensors which (sometimes) are equipped with a high resolution digital camera; data collected: weather data (1 x in 10 min) & image data (1 x in 1 h)
- **Environment Observation and Forecasting System (EOFS)**

  → EOFS components: *sensor stations*, *distribution network*, *centralized processing farm*
  - **CORIE**
    - EOFS prototype for Columbia river; 13 stationary sensor nodes deployed across Columbia river estuary (on buoys) and 1 mobile sensor node drifting off-shore; used to guide vessel transportation and forecasting
  - **ALERT** (**Automated Local Evaluation in Real-Time**)
    - ALERT already deployed in 1970's by National Weather Service (USA): Information provided w. r. t. rainfall and water level (in real-time) to evaluate a potential flooding of regions (in California and Arizona); sensors: e.g., water level, temperature and wind sensors

Applications of Sensor Networks : Examples II

- **Health Applications**
  - **SSIM** (**Smart Sensors and Integrated Microsystems**)

    → retina prosthesis chip consisting of 100 micro sensors implanted within human eye; wireless communications required to provide feedback control, image identification and validation

  - **Other examples**: *Glucose level monitors*, *Organ monitors*, *Cancer detectors*, *General health monitors* (as wireless biomedical sensors embedded in human body) → challenges: systems must be ultra-safe, reliable, minimal maintenance, energy-harnessing from body heat

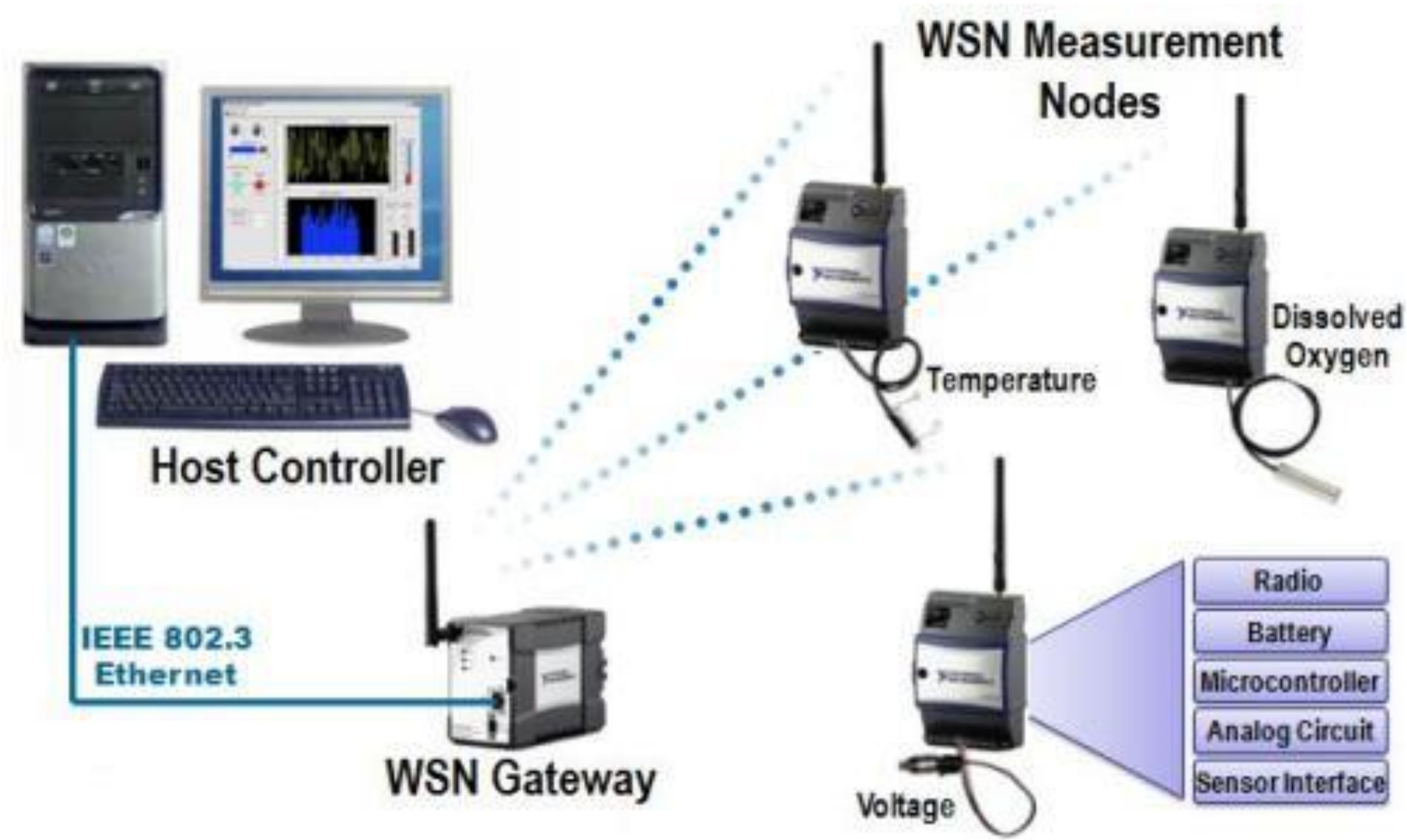
- **Other Applications**
  - **Smart Energy** → improve efficiency of energy provision chain; system components: energy-generation, distribution & consumption infrastructure
  - *Home Applications*, *Office Applications* → e.g. "**Smart Kindergarten**" building sensor-based wireless network for early childhood education (interaction-based instruction method)

WSN Applications – Example of Home Automation: Intel's digital homing → "The Intelligent Home"

1. You come home
2. Sensor detects opening of front door → automatic start of electric kettle to boil some water (tea-time) & turning on of air-conditioner
3. Sensor detects that you sit on sofa (pressure sensor) → automatic turning-on of light on table and/or TV; etc, etc.

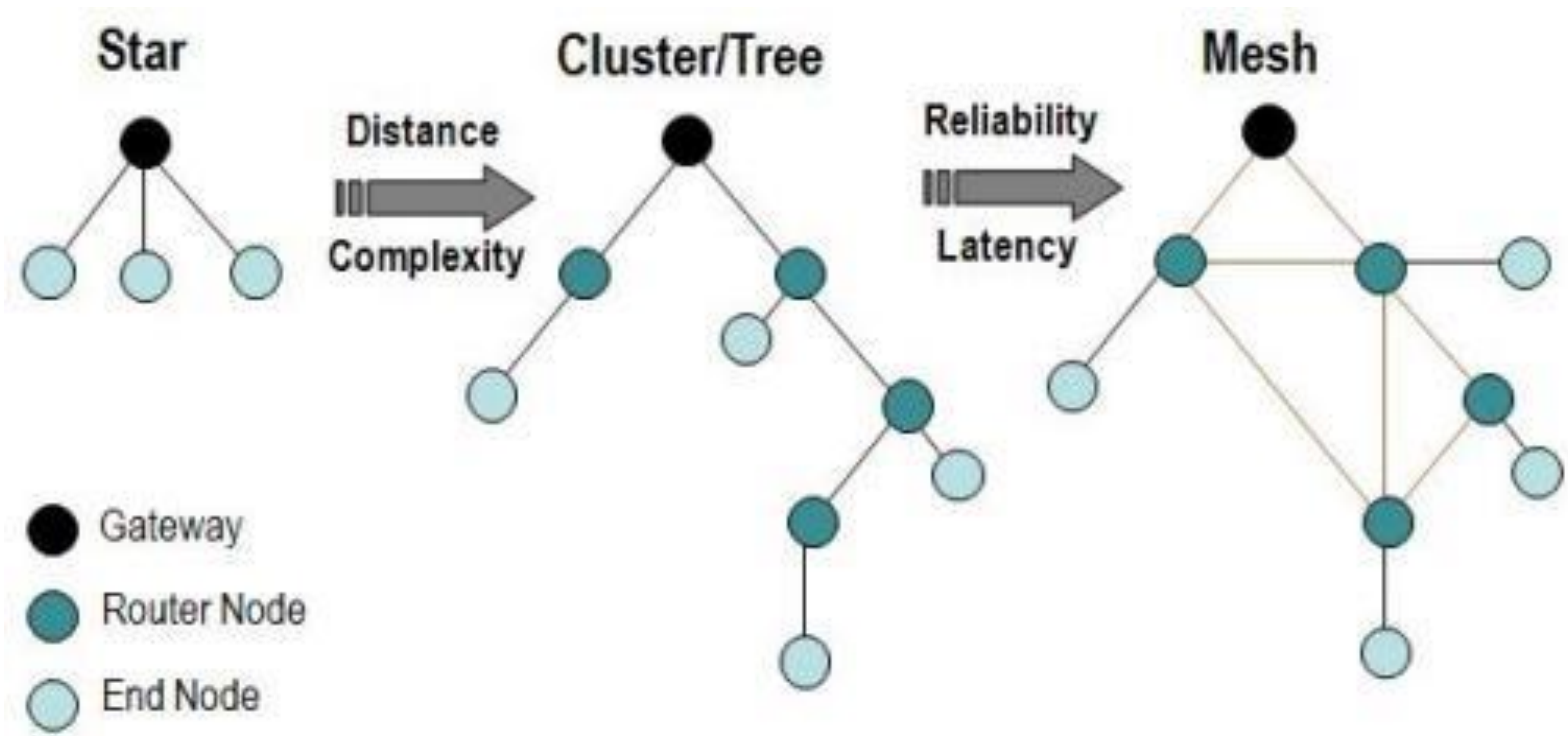
A6.2 Architecture of and Data Transmission via Sensor Networks

Common Wireless Sensor Network Architecture



Quelle f. Abb.: National Instruments (NI) Tutorial vom 23. Juli 2009

Typical WSN Network Topologies



Quelle f. Abb.: National Instruments (NI) Tutorial vom 23. Juli 2009

*Example of a commercially available **WSN Gateway** :*
The NI 9792 Programmable Gateway

Basic properties & characteristics:

- LabVIEW Real-Time Target
- 533 MHz processor
- 2 GB Onboard Storage
- Integrated Web Server
- 2.4 GHz, IEEE 802.15.4 radio to communicate with NI WSN measurement nodes
- Dual Ethernet ports
- -40 to 70°C temperature rating
- 9 to 35 VDC redundant power inputs
- Panel & DIN-Rail Mounting options

Quelle f. Abb.: National Instruments (NI) Tutorial vom 4. Mai 2010

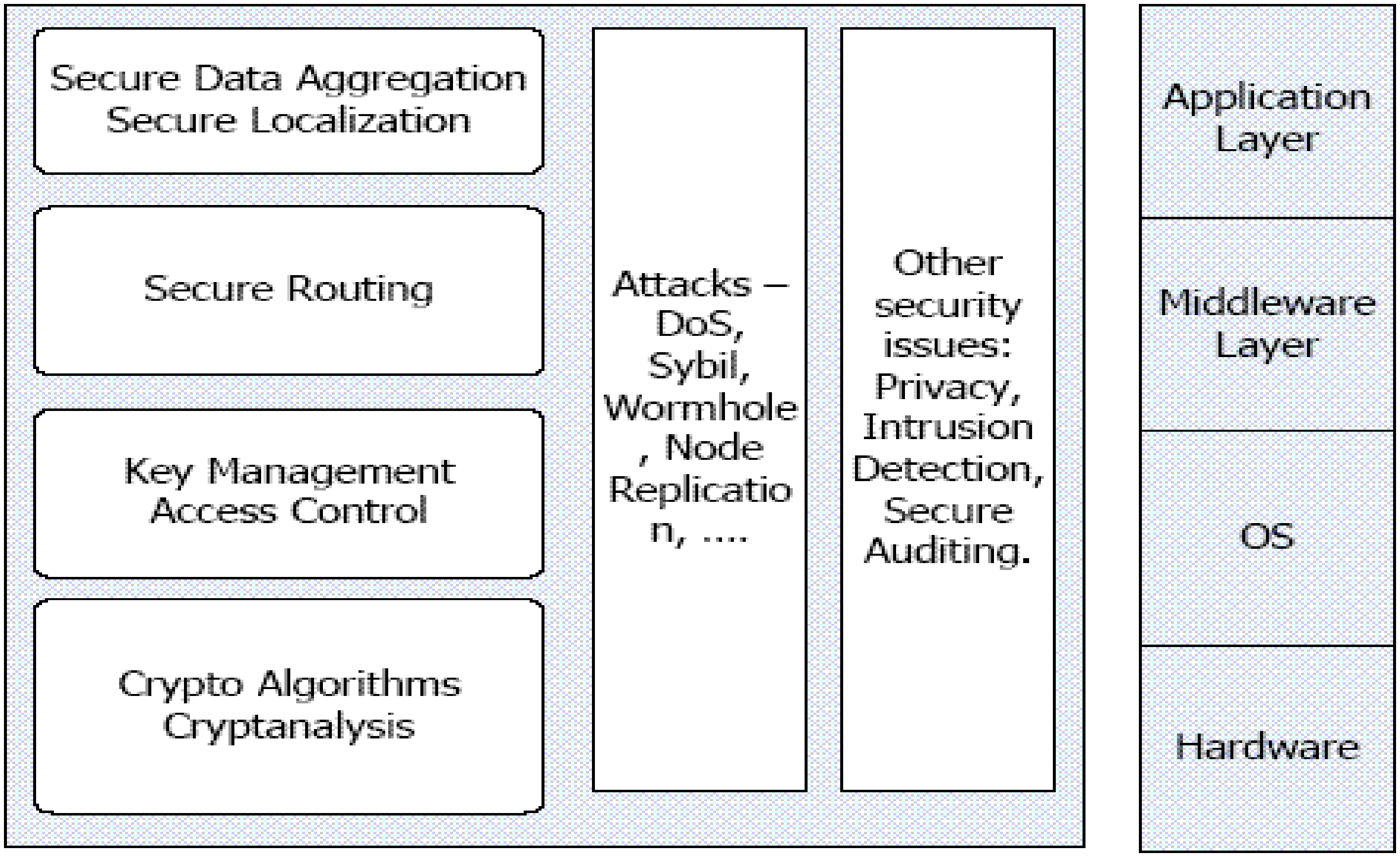
Example of a commercially available ***WSN Measurement Node*** *:*
The NI WSN-3202 Four-Channel, 16-Bit, ±10 V Analog Input Measurement Node

Basic properties & characteristics:

- Battery-powered by 4 AA alkaline cells
- Up to three-year battery life
- Four analog input channels
- Programmable input ranges – ±10, ±5, ±2, and ±0.5 V
- Sensor power output, up to 12 V at 20 mA
- Four digital channels, configurable per channel for input, sinking output, or sourcing output
- -40 to 70°C temperature rating

Quelle f. Abb.: National Instruments (NI) Tutorial vom 4. Mai 2010

Security Architecture for WSN



Quelle f. Abb.:
http://www.wsn-security.info/Security_Map.htm

Wireless Sensor Networks – Some Standards and Specifications

[Source: Wikipedia http://en.wikipedia.org/wiki/Wireless_sensor_network; accesses: May 2010 & May 2012]

Several standards are currently either ratified or under development for WSNs. In addition to the standards, several non-standard, proprietary mechanisms and specifications exist. 6LoWPAN, ISA100, WirelessHART, and ZigBee are all based on the same underlying radio standard: **IEEE 802.15.4 – 2006** (IEEE 802.15 for WPANs, i.e. Wireless Personal Area Networks).

- **6LoWPAN :** working group within IETF that has produced a standards track specification for transmission of IPv6 packets over IEEE 802.15.4.
- **EnOcean :** system for wireless communication in the building automation world; not standardized with any of the generally approved standardization bodies.
- **IEC 62591 :** The International Electrotechnical Commission (IEC) approved the Wireless-HART specification as a full international standard (IEC 62591Ed. 1.0) in April 2010.
- **IEEE 1451 :** The emerging IEEE 1451 attempts to create standards for the smart sensor market; main point of smart sensors : move the processing intelligence closer to the sensing device.
- **ISA100 :** A new standard under development; makes use of 6LoWPAN and provides additional agreements for industrial control applications; Sept. 2009: 1st Release ISA100.11a; 2010 → major corrigendum (by ISA100 standards committee).
- **WirelessHART** standard **:** extension of the HART Protocol; specifically designed for Industrial applications like Process Monitoring and Control. WirelessHART was added to the overall HART protocol suite as part of the HART 7 Specification, which was approved by the HART Communication Foundation in June 2007.
- **ZigBee :** An IEEE standard networking specification intended for uses such as embedded sensing, medical data collection, consumer devices like television remote controls, and home automation. Zigbee is promoted by a large consortium of industry players.