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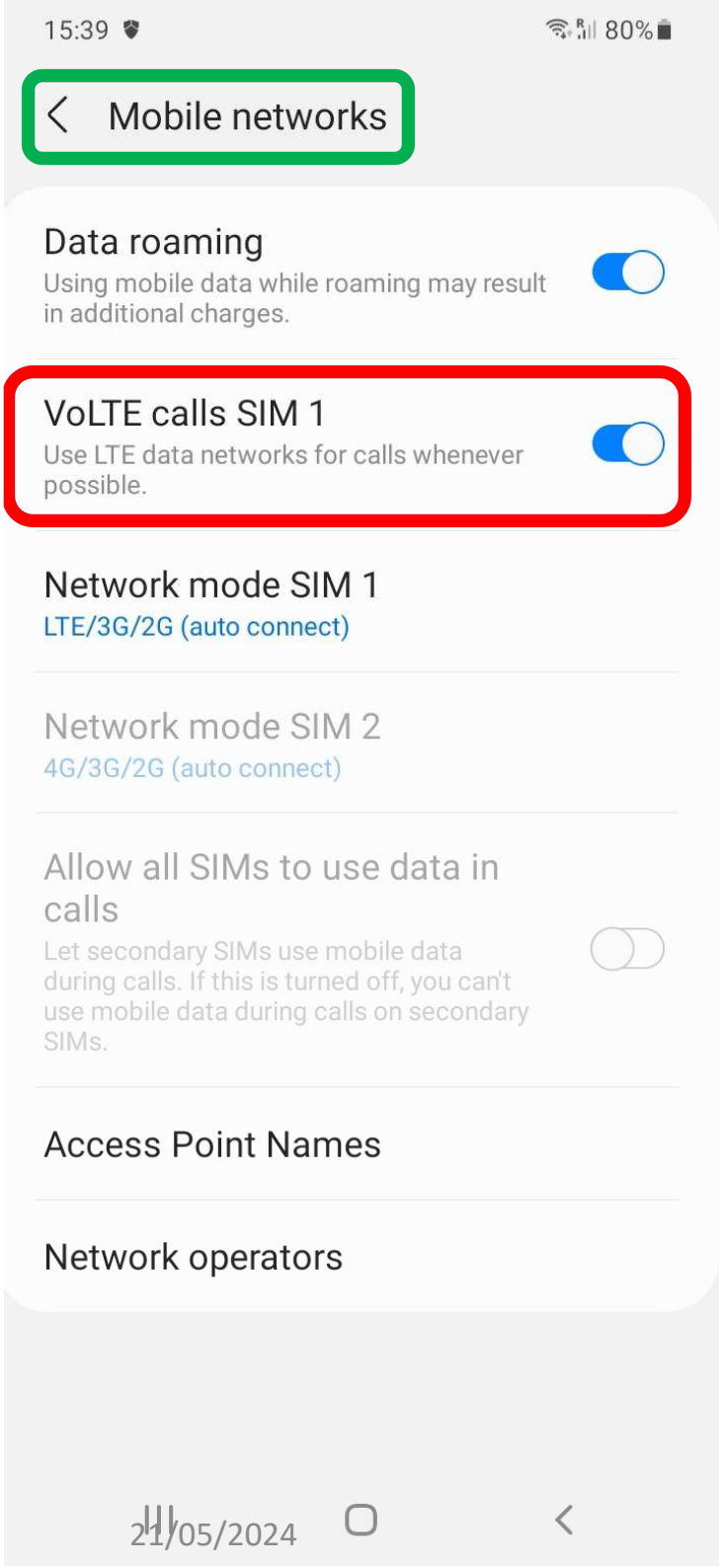
Communication Networks VITMAB06

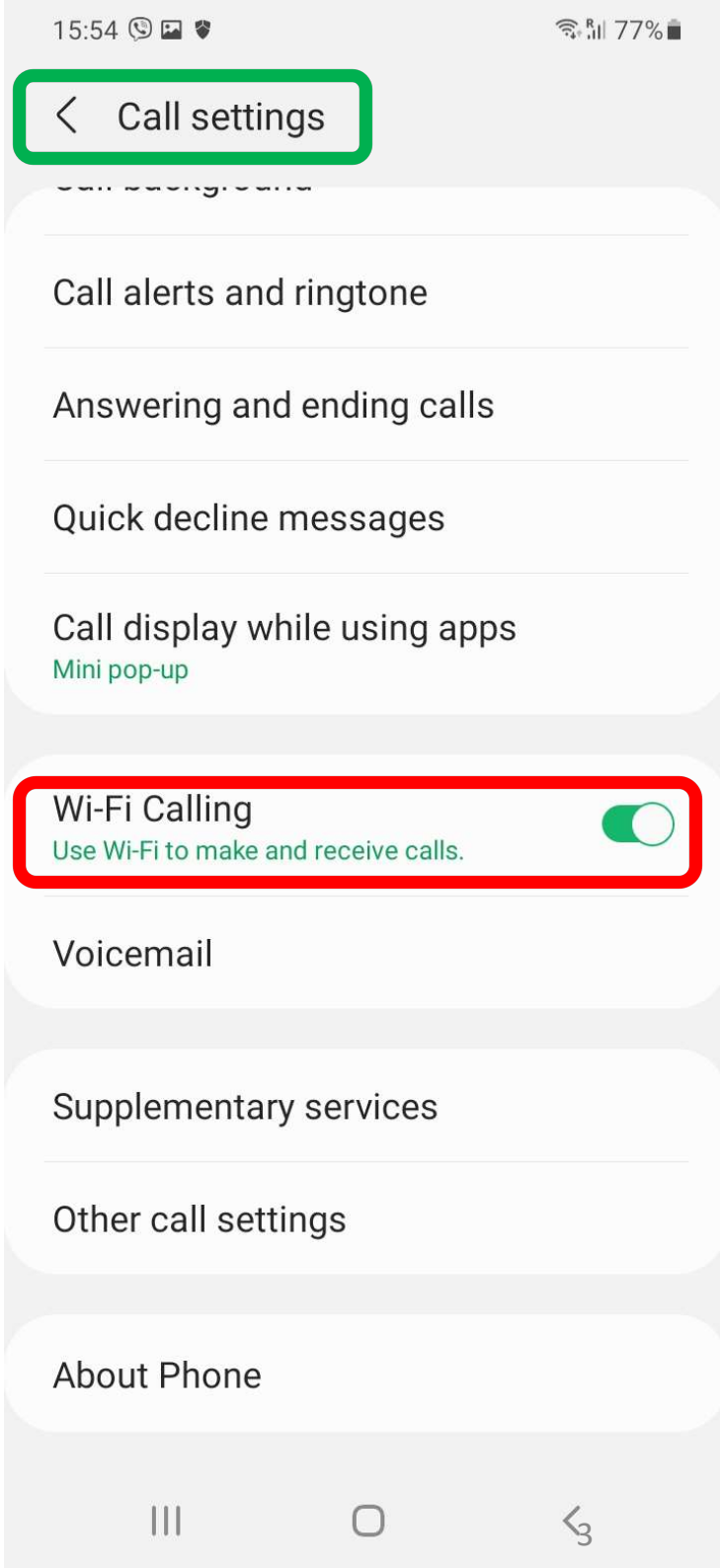
May 21 Tuesday 14:15-15:45
(Fourth (last) presentation by TC)

Today Lesson

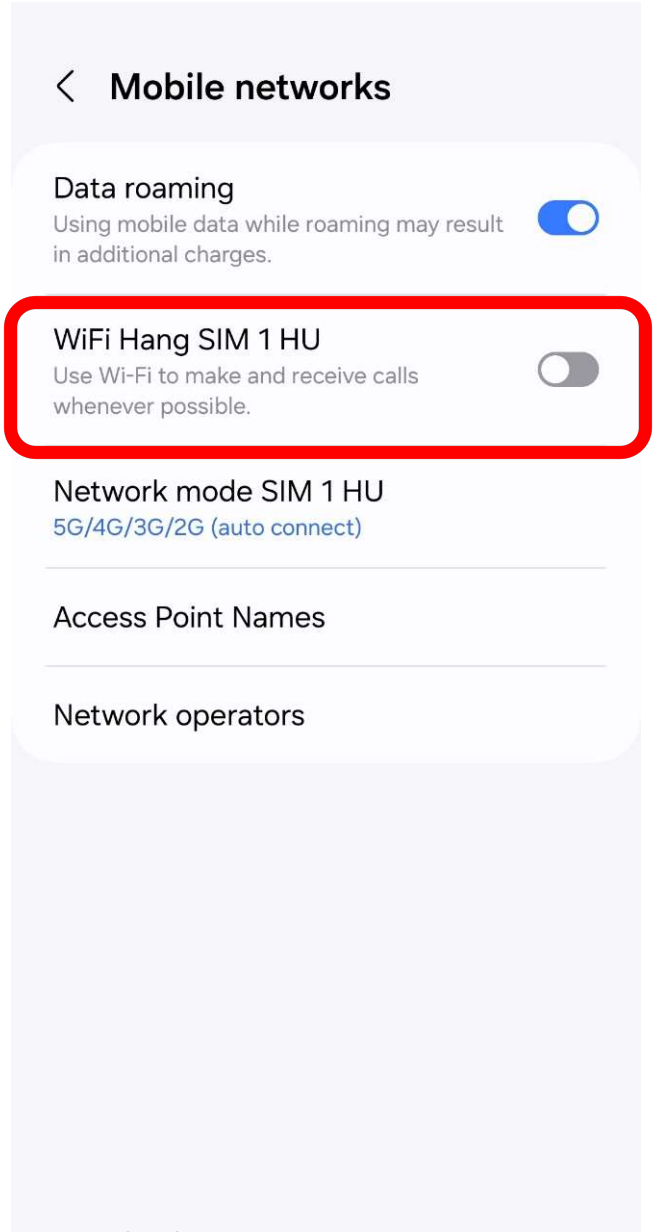
- Wi-Fi
- 3GPP: NTN and TN integration?

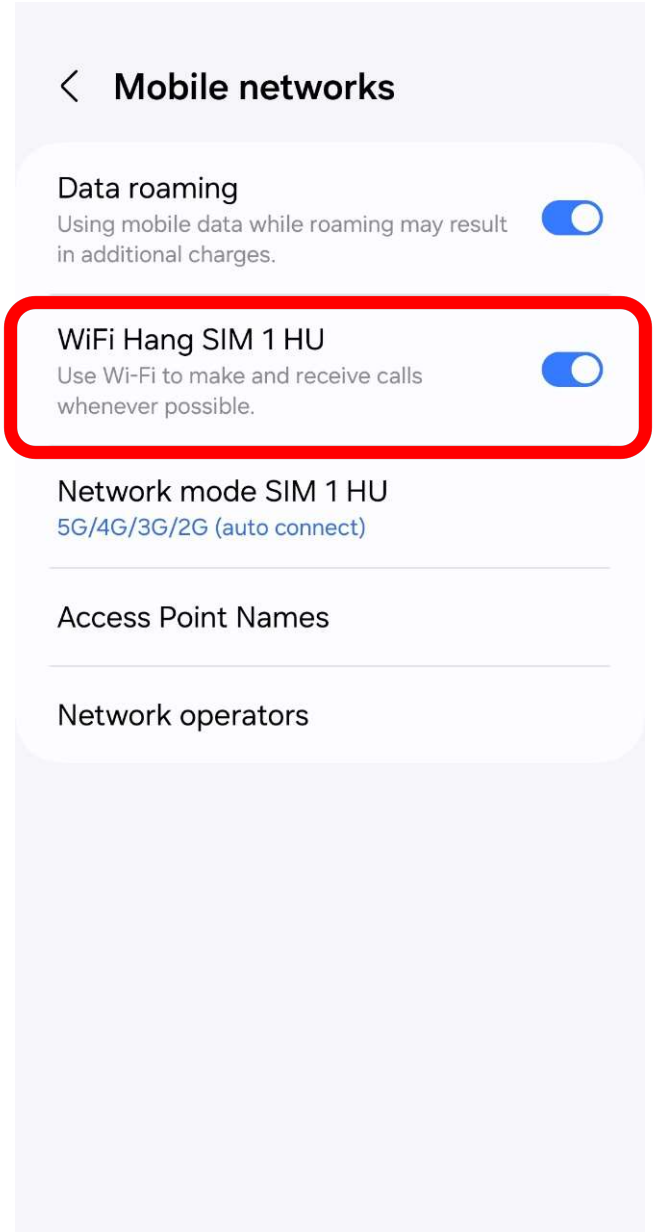


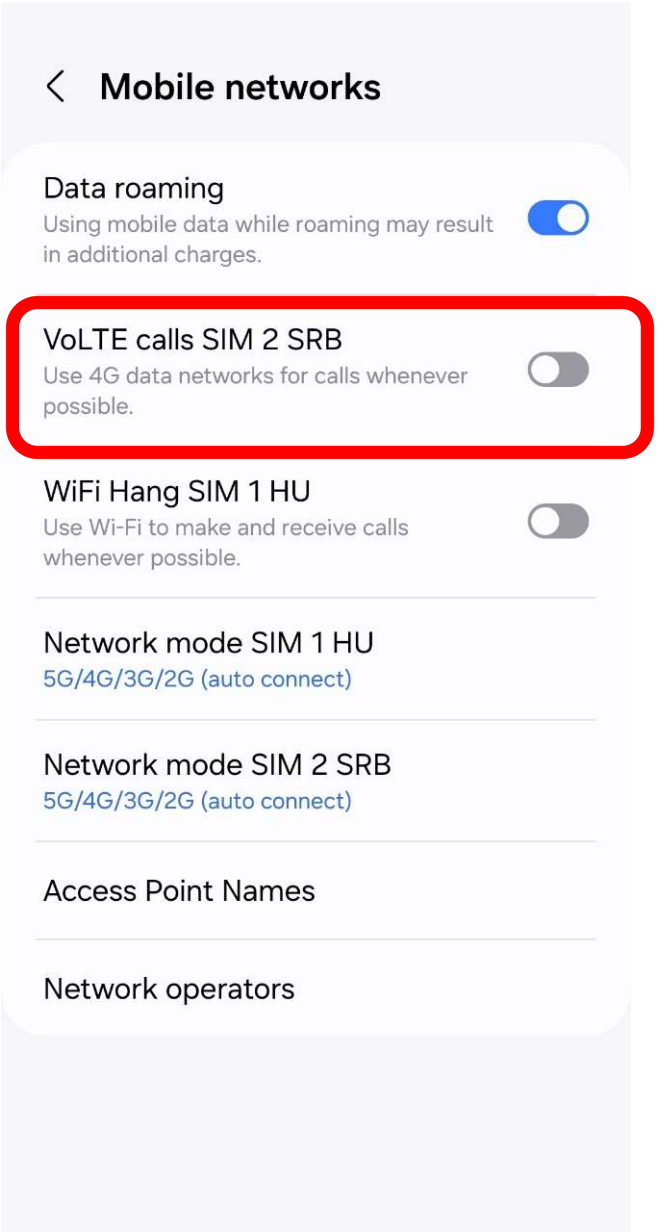
Convergence vs Divergence?

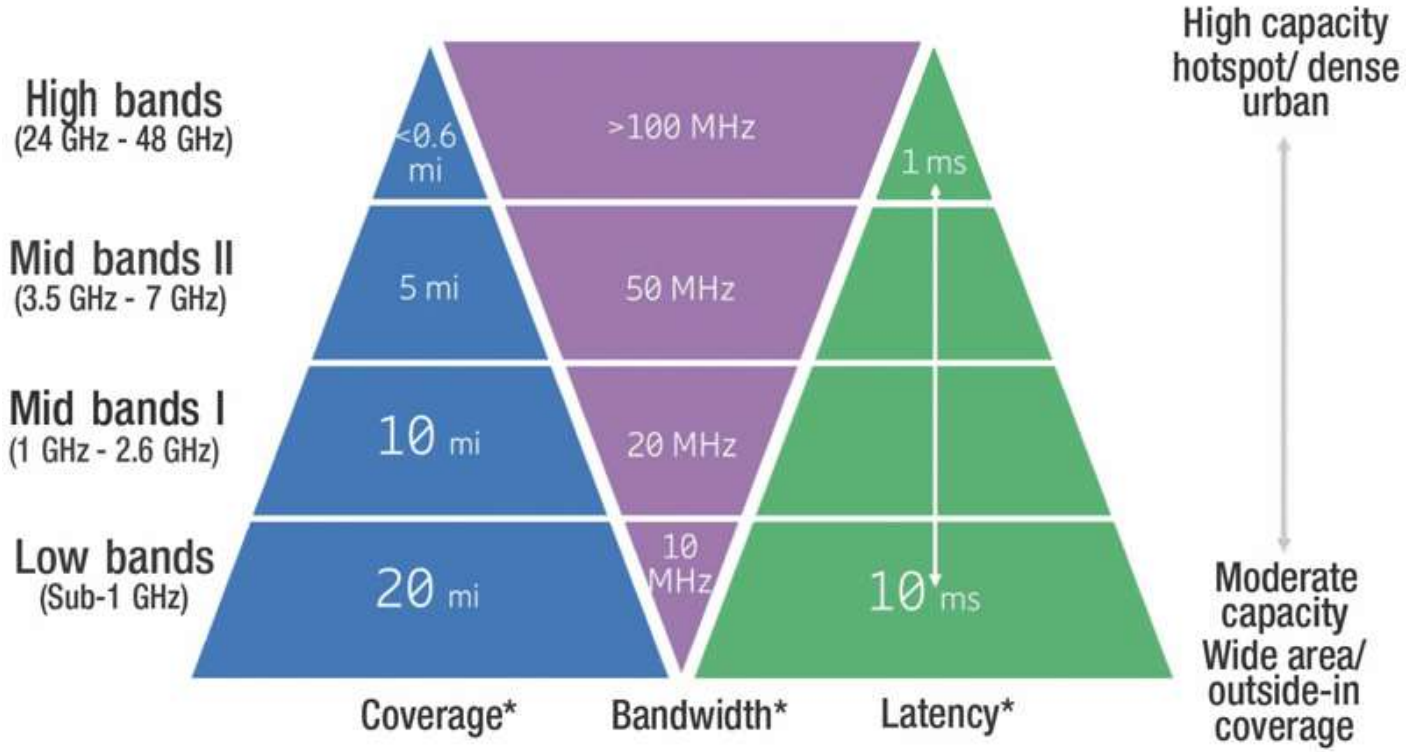


Wi-Fi and Cellular Mobile Convergence



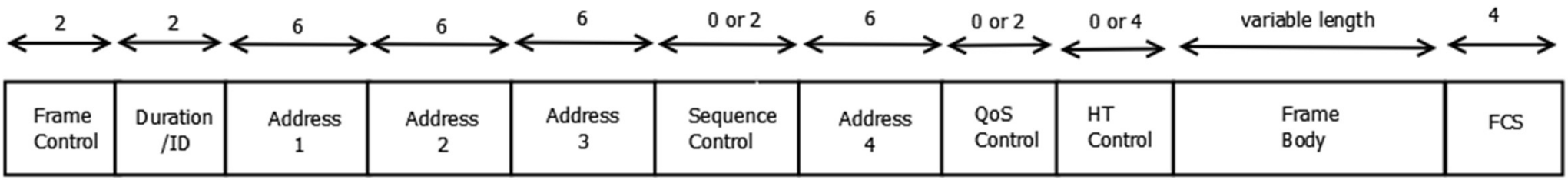





High bands
(24 GHz - 48 GHz)
Mid bands II
(3.5 GHz - 7 GHz)
Mid bands I
(1 GHz - 2.6 GHz)
Low bands
(Sub-1 GHz)
<0.6 mi
>100 MHz
1 ms
5 mi
50 MHz
10 mi
20 MHz
20 mi
10 MHz
10 ms
Coverage*
Bandwidth*
Latency*
High capacity hotspot/ dense urban
Moderate capacity Wide area/ outside-in coverage

Wi-Fi

- https://en.wikipedia.org/wiki/Wi-Fi
- Excellent 20-page material that includes how it operates!
- 802.11 frames very similar to Ethernet frames at the data link layer
- with extra address fields



Wi-Fi Generations

Generation	IEEE Standard	Maximum Linkrate (Mbit/s)	Adopted	Radio Frequency (GHz)[38]
Wi-Fi 7	802.11be	40000	TBA	2.4/5/6
Wi-Fi 6E	802.11ax	600 to 9608	2020	2.4/5/6
Wi-Fi 6			2019	2.4/5
Wi-Fi 5	802.11ac	433 to 6933	2014	5
Wi-Fi 4	802.11n	72 to 600	2008	2.4/5
(Wi-Fi 3*)	802.11g	6 to 54	2003	2.4
(Wi-Fi 2*)	802.11a	6 to 54	1999	5
(Wi-Fi 1*)	802.11b	1 to 11	1999	2.4
(Wi-Fi 0*)	802.11	1 to 2	1997	2.4
*: (Wi-Fi 0, 1, 2, 3, are unbranded common usage.[39][40])				

Wi-Fi Generations

Generation	IEEE standard	Adopted	Maximum link rate (Mbit/s)	Radio frequency (GHz)
Wi-Fi 8	802.11bn	2028	100,000[44]	2.4, 5, 6, 7, 42.5, 71[45]
Wi-Fi 7	802.11be	2024	1376–46,120	2.4, 5, 6[46]
Wi-Fi 6E	802.11ax	2020	574–9608[47]	6[b]
Wi-Fi 6		2019		2.4, 5
Wi-Fi 5	802.11ac	2014	433–6933	5[c]
Wi-Fi 4	802.11n	2008	72–600	2.4, 5
(Wi-Fi 3)*	802.11g	2003	6–54	2.4
(Wi-Fi 2)*	802.11a	1999		5
(Wi-Fi 1)*	802.11b	1999	1–11	2.4
(Wi-Fi 0)*	802.11	1997	1–2	2.4

CSMA/CA

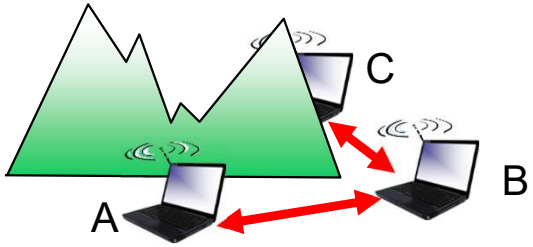
- Ethernet: CSMA/CD
- Wi-Fi: CSMA/CA

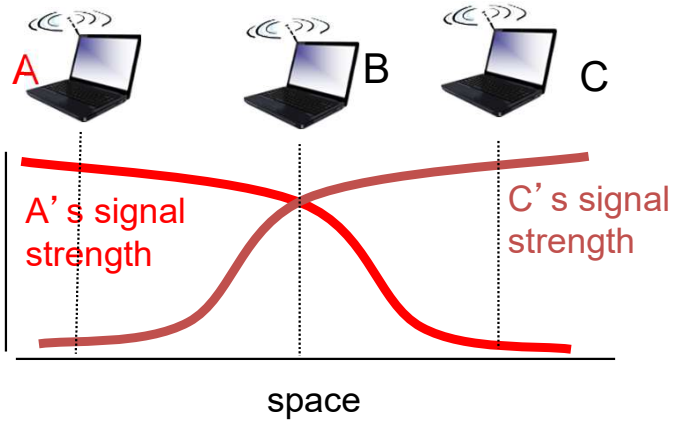
Carrier-sense multiple access with

- collision detection (CSMA/C**D**)
- collision avoidance (CSMA/C**A**)

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)





IEEE 802.11 MAC Protocol: CSMA/CA

802.11 sender

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

transmit entire frame (no CD)

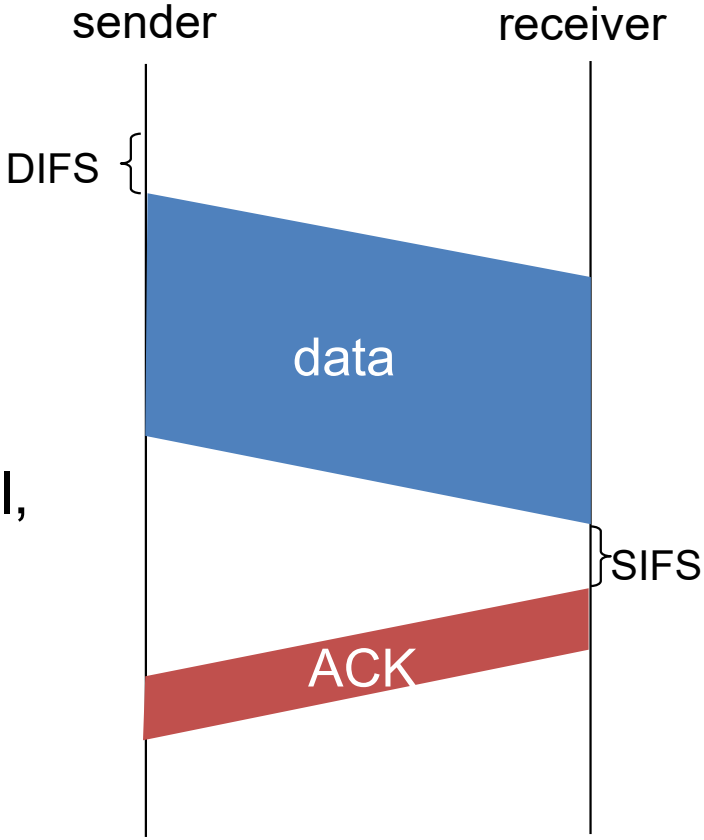
2 if sense channel busy then

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)

DIFS (Distributed Inter-Frame Space) / **SIFS** (Short Inter-Frame Space)

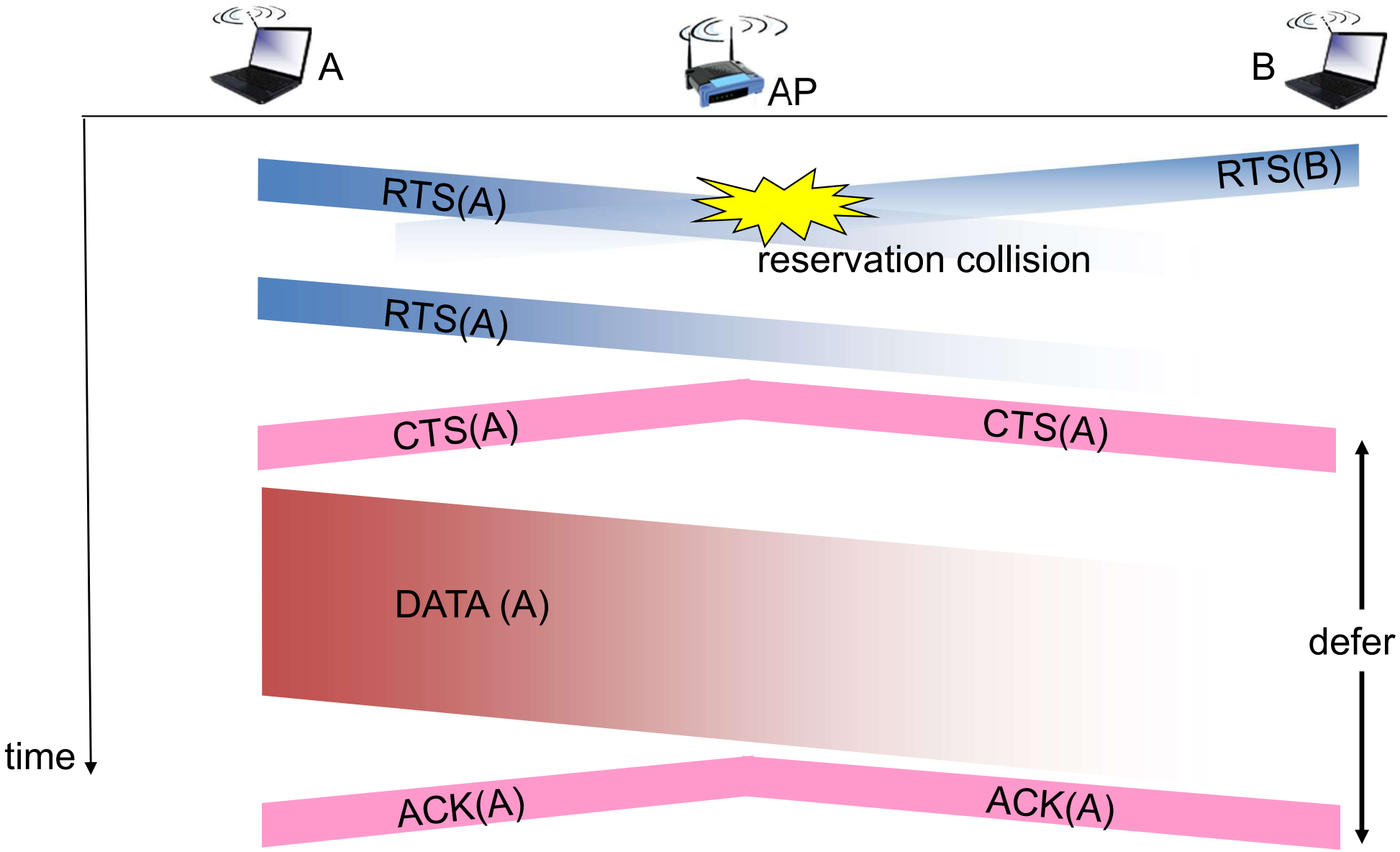
Avoiding collisions (more)

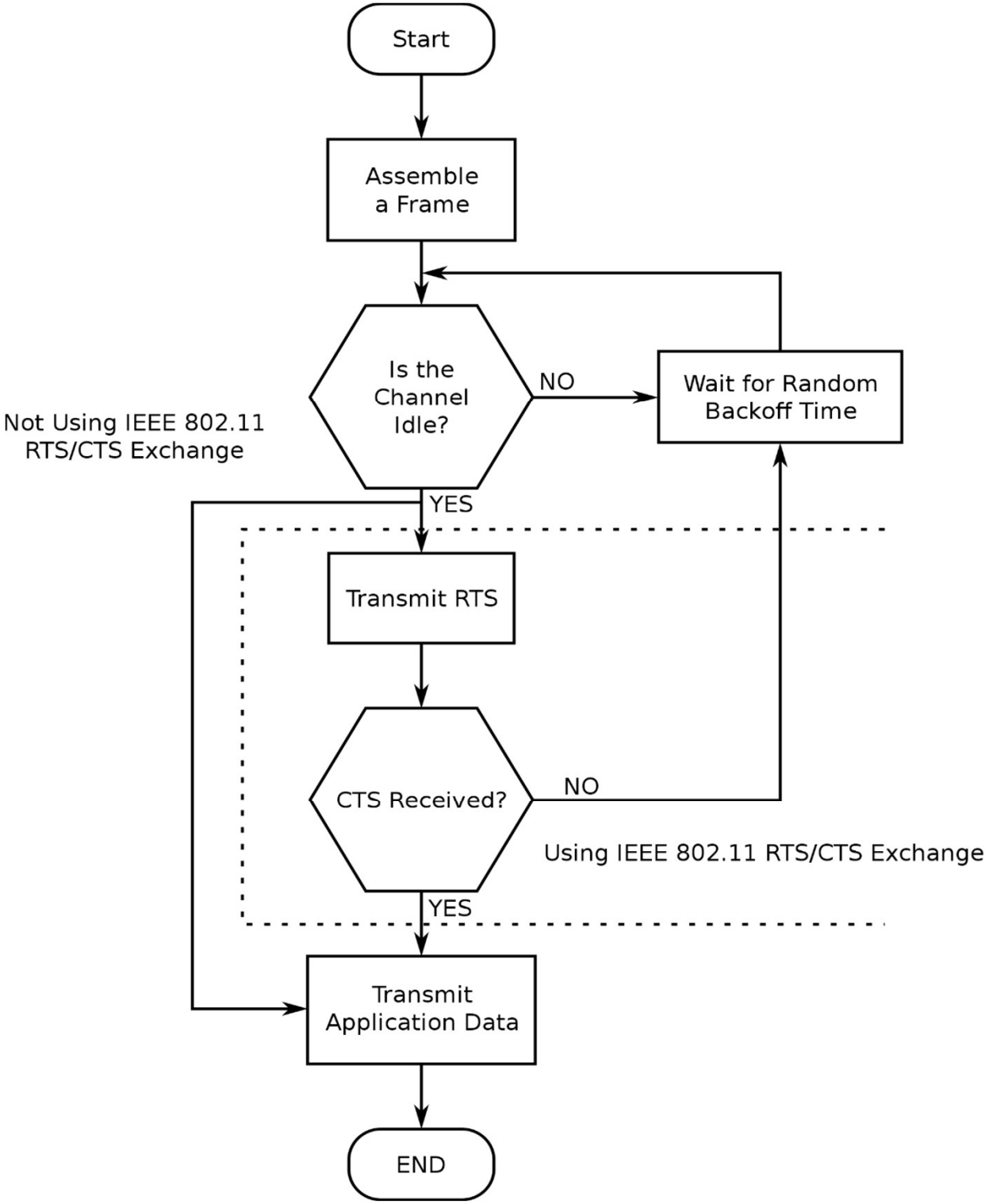
idea: allow sender to "reserve" channel rather than random access of data frames: avoid collisions of long data frames

- 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

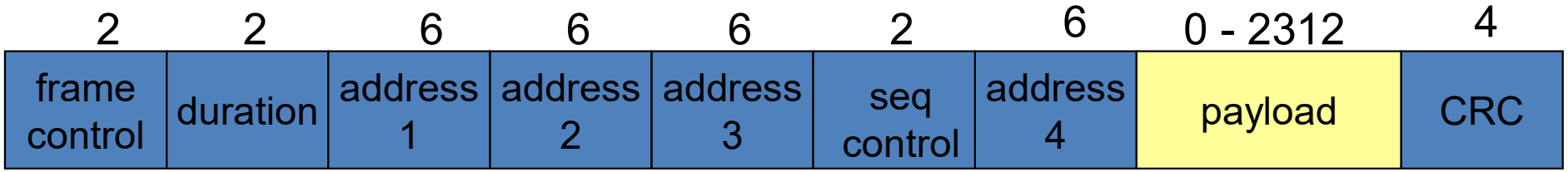
avoid data frame collisions completely using small reservation packets!

Collision Avoidance: RTS-CTS exchange




Start
Assemble a Frame
Is the Channel Idle?
NO
Wait for Random Backoff Time
Not Using IEEE 802.11 RTS/CTS Exchange
YES
Transmit RTS
CTS Received?
NO
Using IEEE 802.11 RTS/CTS Exchange
YES
Transmit Application Data
END

802.11 frame: addressing



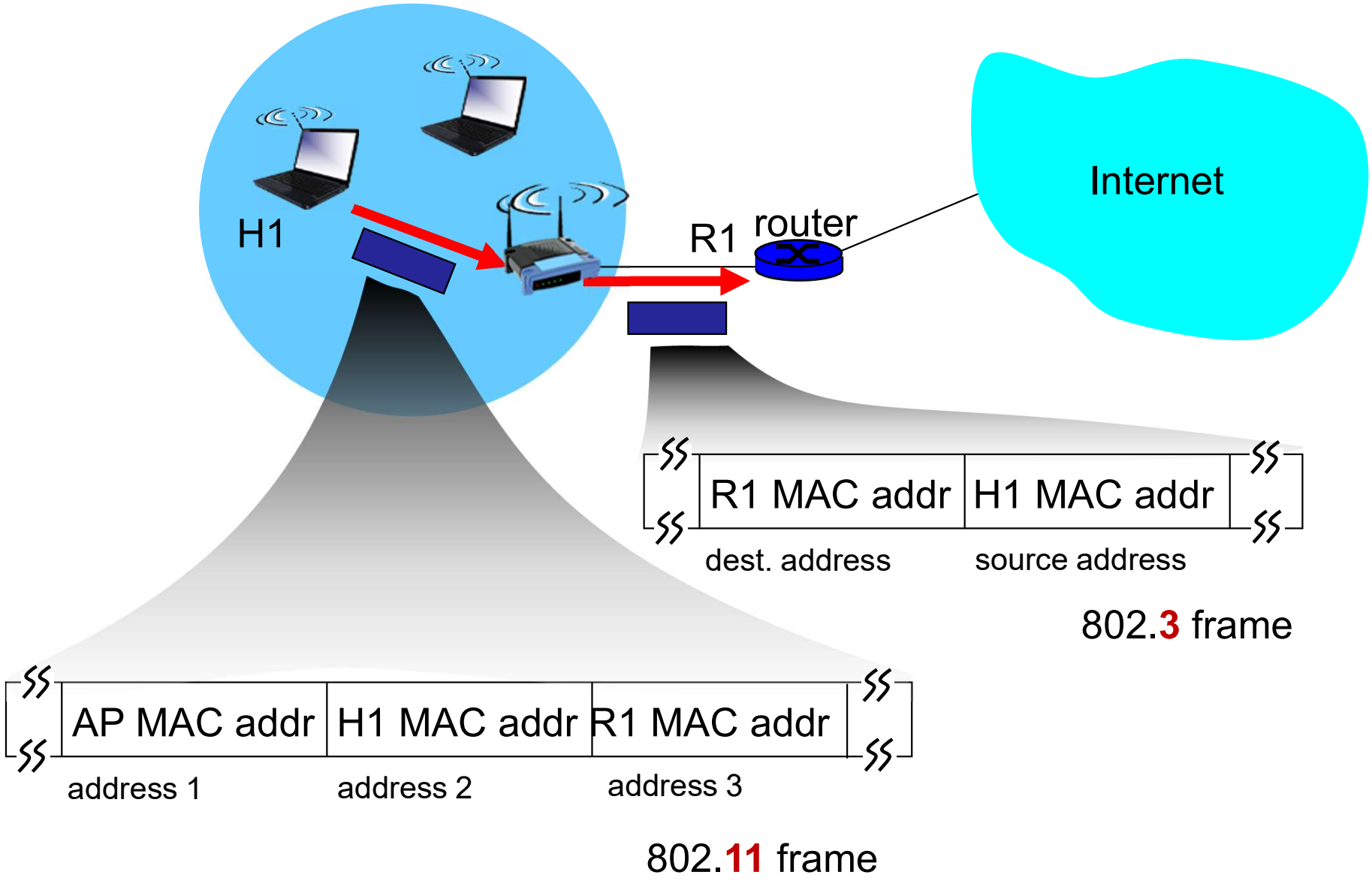
Address 1: MAC address of wireless host or AP to receive this frame **DST**

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

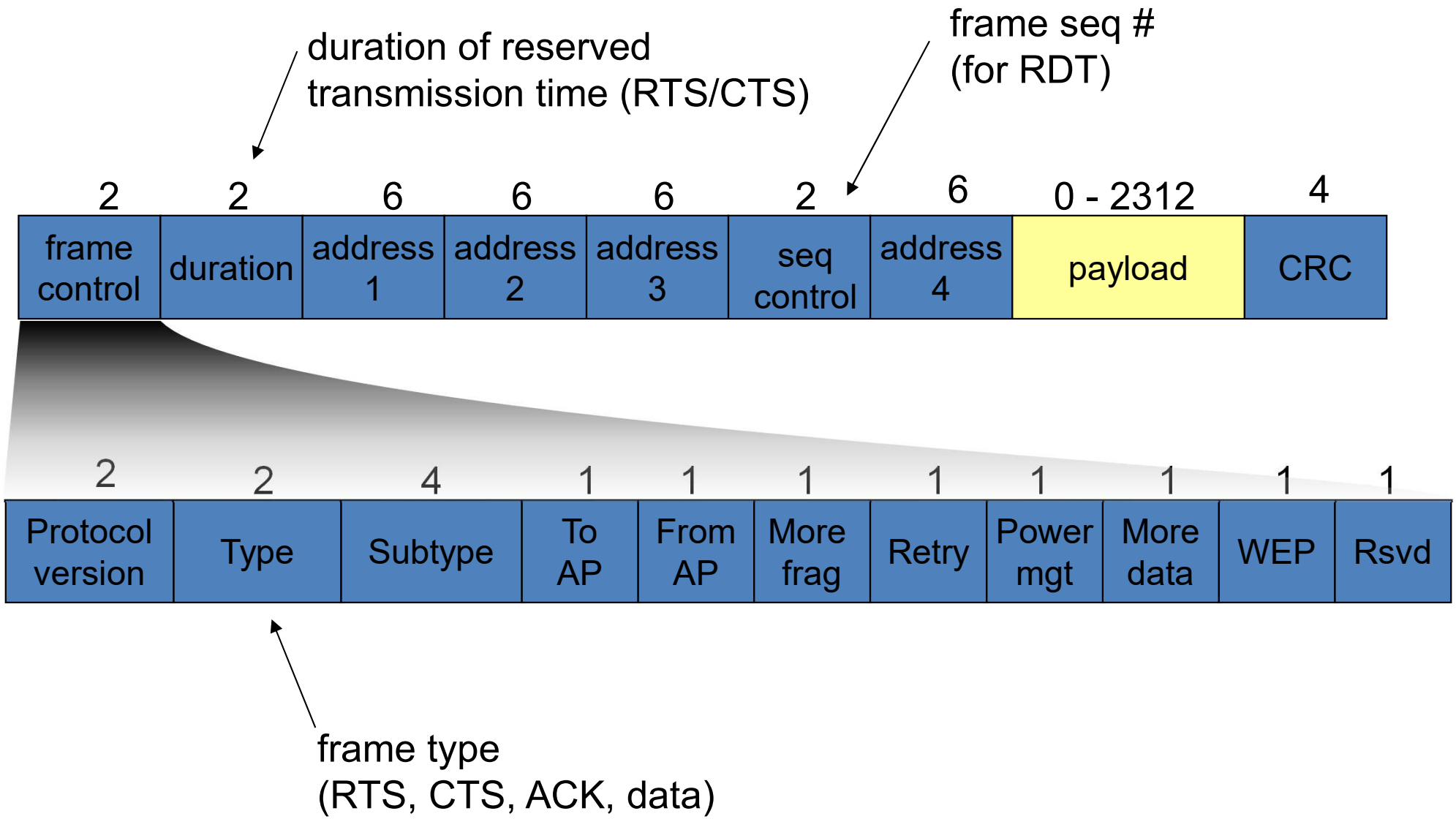
Address 3: MAC address of router interface to which AP is attached

Address 4: used only in ad hoc mode

802.11 frame: addressing

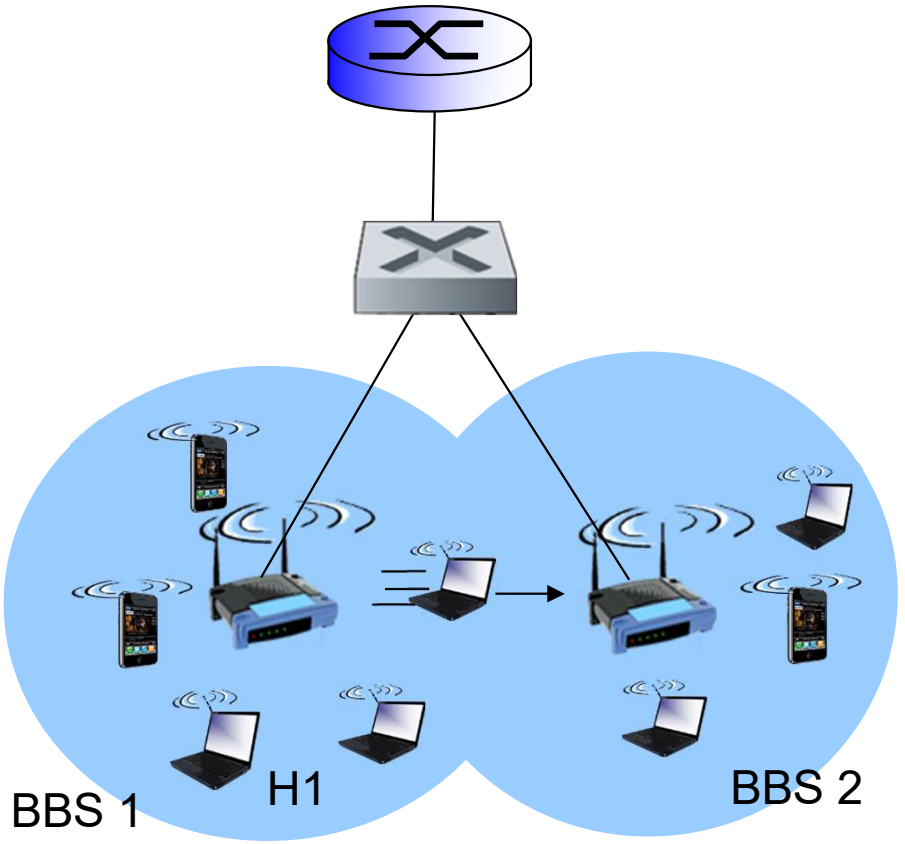


802.11 frame: more



802.11: mobility within same subnet

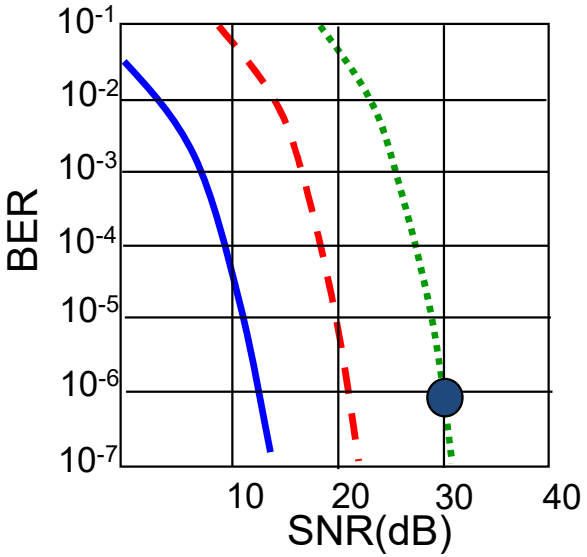
- H1 remains in same IP subnet: IP address can remain same
- switch: which AP is associated with H1?
  - self-learning (Ch. 5): switch will see frame from H1 and "remember" which switch port can be used to reach H1

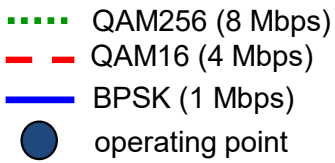


802.11: advanced capabilities

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

Irfan Yousaf:
IoT DEVICES, Wi-Fi 6E AND Wi-Fi 7

https://www.iot-now.com/2024/04/04/143489-iot-devices-wi-fi-6e-and-the-future-of-wi-fi-7/?reg=success
http://www.iot-now.com_Wi-Fi-6E-whitepaper.pdf

- **The IoT connectivity considerations we all face** - Bandwidth, range and power consumption are the main ones. But reliability, cost, latency, mobility, compatibility with existing infrastructure, future-proofness, scalability and installation location also matter.
- **The emergence of Wi-Fi 6E** - Since 2019, Wi-Fi 6 (IEEE 802.11ax) has been improving the performance of IoT in dense environments like offices, shopping areas and buildings. It's faster and supports 8X8 connections for both uplink and downlink.
- **Wi-Fi 6E's benefits in IoT Devices** - This technology offers an added frequency band, better power consumption and battery life, faster data rates, MU-MIMO & beamforming, improved latency and enhanced security.
- **The Future with Wi-Fi 7** - Maximum data rates will go to 46 Gbps and offer 4096-QAM compared to 1024-QAM in Wi-Fi 6E. It adds multi-chassis link aggregation (MLAG) and operation; coordinated beamforming; MU-MIMO 16x16; flexible channel utilisation and more.
- **How to improve antenna performance** - There are often challenges in finding the right antennas for seamless connectivity. That's why having a trusted RF technology partner with varied capabilities and expert support early in the design phase is critical.

https://www.iot-now.com/2024/04/04/143489-iot-devices-wi-fi-6e-and-the-future-of-wi-fi-7/?reg=success

COMPARISON OF DIFFERENT IOT CONNECTIVITY TECHNOLOGIES

- bandwidth, range and power consumption

Technology	Bandwidth	Coverage	Power Consumption	Cost
4G/5G	High	High	High	High
LTE-M	Medium	High	Low	Low
NB-IoT	Low	High	Low	Low
LoRa	Low	High	Low	Low
Sigfox	Low	High	Low	Low
Wi-Fi	High	Low	High	Medium
Zigbee	Medium	Low	Medium	Low
Bluetooth	Medium	*Low	High	Low

https://www.iot-now.com/2024/04/04/143489-iot-devices-wi-fi-6e-and-the-future-of-wi-fi-7/?reg=success

BASIC PARAMETER COMPARISON OF 802.11AC AND 802.11AX

	IEEE 802.11ac (Wi-Fi 5)	IEEE 802.11ax (Wi-Fi 6/6E)
Bands	5 GHz	2.4, 5, 6 GHz
Channel Bandwidth	20, 40, 60, 160 MHz	20, 40, 60, 160 MHz
Subcarrier Spacing	312.5 KHz	78.125 KHz
Symbol Duration	3.2 us + 0.8/0.4 us	12.8 us + 0.8/1.6/3.2 us
Highest Modulation	256-QAM	1024-QAM
Max Data Rate	6933 Mbps	9607.8 Mbps

https://www.iot-now.com/2024/04/04/143489-iot-devices-wi-fi-6e-and-the-future-of-wi-fi-7/?reg=success

BASIC PARAMETER COMPARISON OF IEEE 802.11AC AND IEEE 802.11AX

	Wi-Fi 6	Wi-Fi 7
IEEE Standard	802.11ax	802.11be
Maximum Transmission Rate	9.6 Gbps	46 Gbps
Frequency Band	2.4 GHz, 5 GHz, 6 GHz (Wi-Fi 6E)	2.4 GHz, 5 GHz, 6 GHz
Security Protocol	WPA3	WPA3
Channel Bandwidth	20 MHz, 40 MHz, 80 MHz, 160 MHz, 80+80 MHz	Up to 320 MHz
Modulation Mode	1024-QAM OFDMA	4096-QAM OFDMA
MIMO	8x8 UL/DL MU-MIMO	16x16 UL/DL MU-MIMO

- MU-MIMO and Beamforming
  - MIMO
    - multiple streams to a single user
  - MU-MIMO
    - spatial streams to multiple users simultaneously
    - improves network efficiency
      - Wi-Fi 6E: MU-MIMO 8X8— uplink and downlink
      - Wi-Fi 5: limited to 4X4 only in downlink
- “Meshing”
  - multi-hop connections
  - meshing-capable devices – some or all

- TN in general
- NTN in general
- TN and NTN convergence / integration

Global Optical Cable Infrastructure

https://submarine-cable-map-2024.telegeography.com/

Satellites in early communications

- Television broadcast satellites
- Telephony relay satellites
- GNSS (Global Navigation Satellite System)
  - Synchronization!!! and global positioning
  - GPS (USA)
  - BeiDou / BDS (China)
  - Galileo (Europe)
  - GLONASS (Russia)
  - IRNSS / NavIC (India)
  - QZSS (Japan)
- https://www.gps.gov/systems/gnss/#:~:text=Global%20navigation%20satellite%20system%20(GNSS,a%20global%20or%20regional%20basis

Convergences (3./3)

- Non-Terrestrial and Terrestrial (3GPP) Networks
  - https://lr-resources.lightreading.com/?p=w_quam141&w=d&email=70bcaeea1dabc1c2fb343822772989df&key=WRtAXXJKZ3xtrj7587UH&ts=37516&u=08605917509517137206 47&e=Y2lua2xlckB0bWl0LmJtZS5odQ==&secure=1&_afn=0
- “space-to-handset” and “space-to-IoT”
- According to satellite operator Iridium TNs cover:
  - 20% of the globe’s surface and
  - 40% of the landmass
- network connectivity need:
  - Cover unserved, remote areas

LEO – MEO – GEO

Constellations:

- Low Earth Orbit (LEO)
- Medium Earth Orbit (MEO)
- Geostationary Equatorial Earth Orbit (GEO)

LEO pro et contra

Pro:

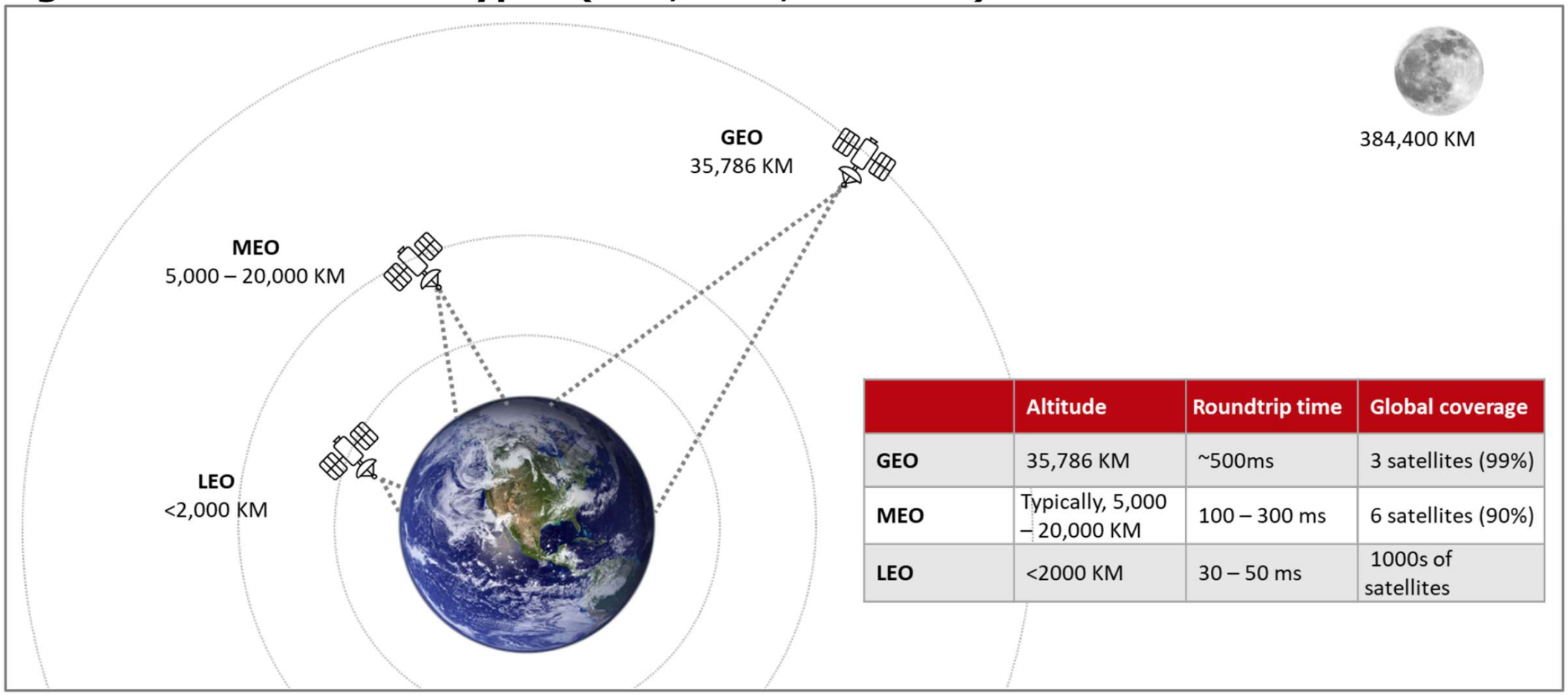
- lower latency
- lower path loss
- greater area capacity density
- Relative to GEO systems, LEO satellites are roughly half the cost per kilogram to launch

Contra:

- LEO satellite cell sizes are smaller, which drives the need for more satellites
- they move rapidly relative to the Earth's surface (7.8 kilometers per second) (28 080 km/h) (23 MACH)
  - channel conditions are highly variable
  - Doppler effect (shift)
  - frequent reselection of "Earth-moving cells"(cells move fast) (frequent handover)
- Lifespan is shorter, as low Earth orbits degrade faster

LEO – MEO – GEO

Figure 1: Constellation types (LEO, MEO, and GEO)



	Altitude	Roundtrip time	Global coverage
GEO	35,786 KM	~500ms	3 satellites (99%)
MEO	Typically, 5,000 – 20,000 KM	100 – 300 ms	6 satellites (90%)
LEO	<2000 KM	30 – 50 ms	1000s of satellites

Source: Heavy Reading

Communication Satelite Systems

- GEO 36 000 km from Earth surface
- MEO (2 000-36 000 km)
- LEO (160-2 000 km)

- Inmarsat www.inmarsat.com
  - Voice, data, M2M
- Iridium www.iridium.com
  - Voice, data, IoT
- Thuraya www.thuraya.com
  - Voice, data, IoT/M2M

- Spacex Starlink Mission www.spacex.com www.starlink.com/
  - Internet services, VLEO → LEO (https://en.wikipedia.org/wiki/Starlink)
- Etc., etc., etc…

HomeWork:Think and calculate!

- If there are two distant points on the Globe to be connected, what is faster (smaller transmission delay)?
  - A) using fiber-optical communications
  - B) using a satellite system?
- Hints:
  - speed of light in vacum or air vs speed of light in SiO2 (~300 000 000 m/s vs ~200 000 000 m/s)
  - Altitude of satellites: ~550 km (https://www.space.com/spacex-starlink-satellites.html) 3,67 msec delay going up+down… and (R + 550 km) · π
  - Non of air-distance, but longer zig-zag….

- On May 21, 2024 we stopped here
- What comes after this is for reading only, i.e., on the exam there will be no questions from the material of this file after this slide.

NTN convergence

- SkyPhone – converged smartphone and satellite phone
- 3GPP NTN
- TN and NTN convergence
- LEO, HAPS, Planes, Ground Stations…

- (Thursday Class – More Details)
  - LEO, VLEO, HAPS, Ground Stations, AeroPlane Communications, etc.

Conventional SmartPhones connect…

- Apple:
  - emergency messaging for iPhone 14 smartphone in partnership with Globalstar
  - commercially available in multiple markets
  - only emergency messaging on the latest generation of handsets
  - still, pioneer service in this category

  - LTE and 5G… and 6G…

Space-to-device partnerships

*Subject to regulations, ** Subject to handset manufacturer interest, Source: Heavy Reading

Partnership	Summary	Spectrum	Launch progress	Offer
Globalstar / Apple	LEO satellites; 2nd gen system; transparent architecture	L- and S-band spectrum	First commercial launch in the category	Emergency messaging for iPhone 14
Iridium/ Qualcomm	LEO satellites; 2nd gen system	L-band spectrum	First services to launch in 2H23**	Two-way messaging focused on Android smartphone ecosystem
Starlink/T-Mobile US	Starlink LEO system (modified?)	Terrestrial PCS spectrum to unmodified handsets*	Testing to begin in 2023; commercial services from 2024	Global MNO wholesale offer
Lynk/Spark	LEO; limited constellation so far (seeking funding)	Terrestrial spectrum to unmodified handsets*	Trial of direct-to-handset service in New Zealand	Global MNO wholesale offer
AST/Vodafone, AT&T, Rakuten	LEO system; limited constellation so far; transparent architecture; phased-array satellites	Terrestrial spectrum to unmodified handsets*	Funded for phase 1 launch; first call 2Q23	Agreements with 40 mobile operators
Inmarsat/ MediaTek/Bullitt	GEO system	L-band	First services to launch in 2H23	Two-way messaging to handsets using NB-IoT module

3GPP NTN 5G Services

- 3GPP Release 17 in 2022
- Two major components (both in sub-7GHz):
  - 5G NR for NTN (NR-NTN)
  - IoT for NTN (IoT-NTN (NB-IoT))

Source: Heavy Reading, Thales Alenia Space

	IoT-NTN	NR-NTN	
	Direct connectivity (<7GHz)		**Indirect connectivity (<7GHz)**
Device type	IoT modules, devices, and gateways	Smartphones, cars, other embedded devices	VSAT and ESIM devices
Performance	Narrowband (10s of kbps)	1–10Mbps	Broadband (50Mbps+)
Radio interface	NB-IoT and eMTC	5G NR	5G NR
Example use cases	Utilities, agriculture, mining, oil & gas, logistics, environmental monitoring	Direct-to-handset: consumer smartphones, public safety, defense, agriculture, utilities, transportation	Cell backhaul, enterprise access, on-demand connectivity, transportation, public safety, defense, etc.
Spectrum	L- and S-bands (n255 and n256)	L- and S-bands (n255 and n256)	Likely in Ka-band (Ku-bands in early stages)

NR-NTN Frequency Ranges

- FR1 (sub-7GHz)
  - for narrowband space-to-handset services
  - up to 1–2Mbps initially
- FR2 (above 7GHz)
  - for broadband VSAT services (50Mbps+)
  - for aircraft, ships, and fixed access

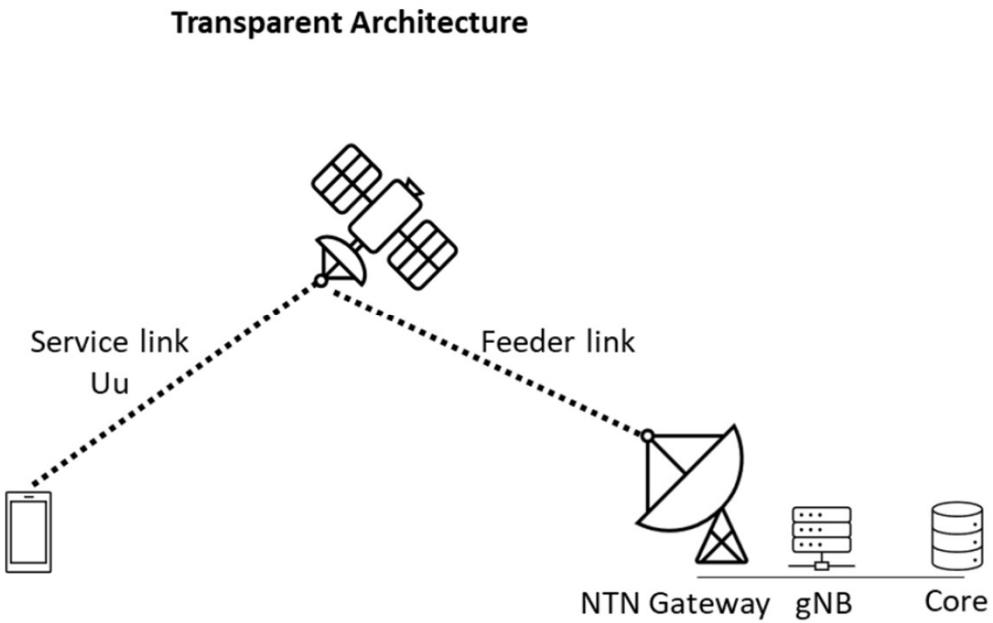
Transparent and Regenerative architectures

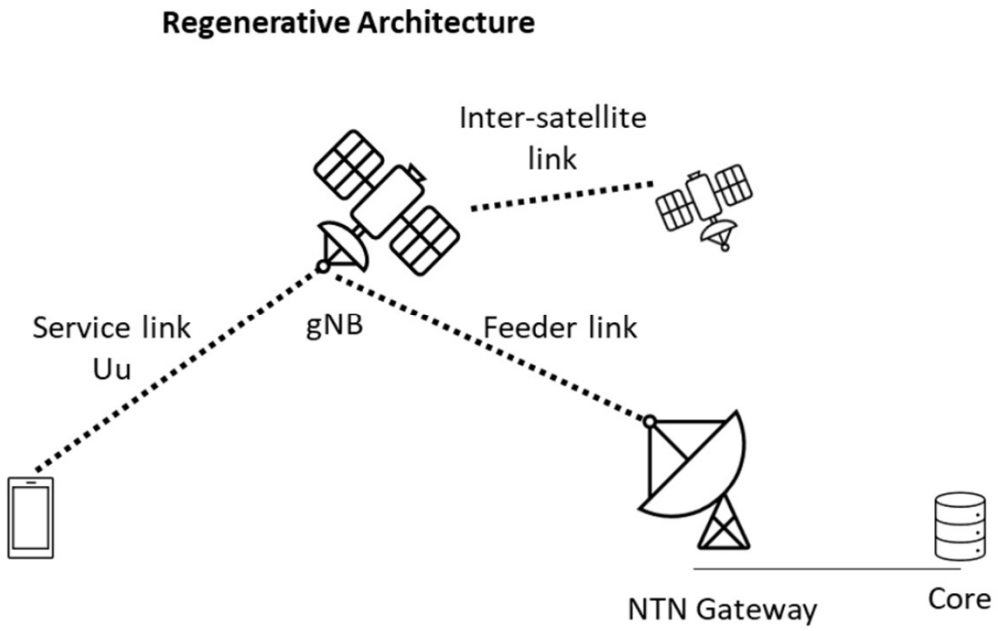
- transparent / “bent pipe” architecture
  - the satellite payload handles the
    - RF filtering, conversion, and amplification
    - the terrestrial signal is unchanged and processed in the base station (gNB) located at the NTN gateway at the ground station
  - The advantage of this architecture is that
    - it simplifies the satellite payload
    - allows greater flexibility to reconfigure or update the terrestrial baseband

Transparent and **Regenerative** architectures

- Expected from Rel.19
- the full gNB is part of the satellite payload
- allows for a more optimized service link
  - (again over the standard Uu interface)
  - because the baseband can adapt faster to channel conditions
- It also allows for inter-satellite links
  - which can be useful if the satellite operator
  - for example, has a limited number of high capacity ground stations and needs to backhaul traffic to a home country

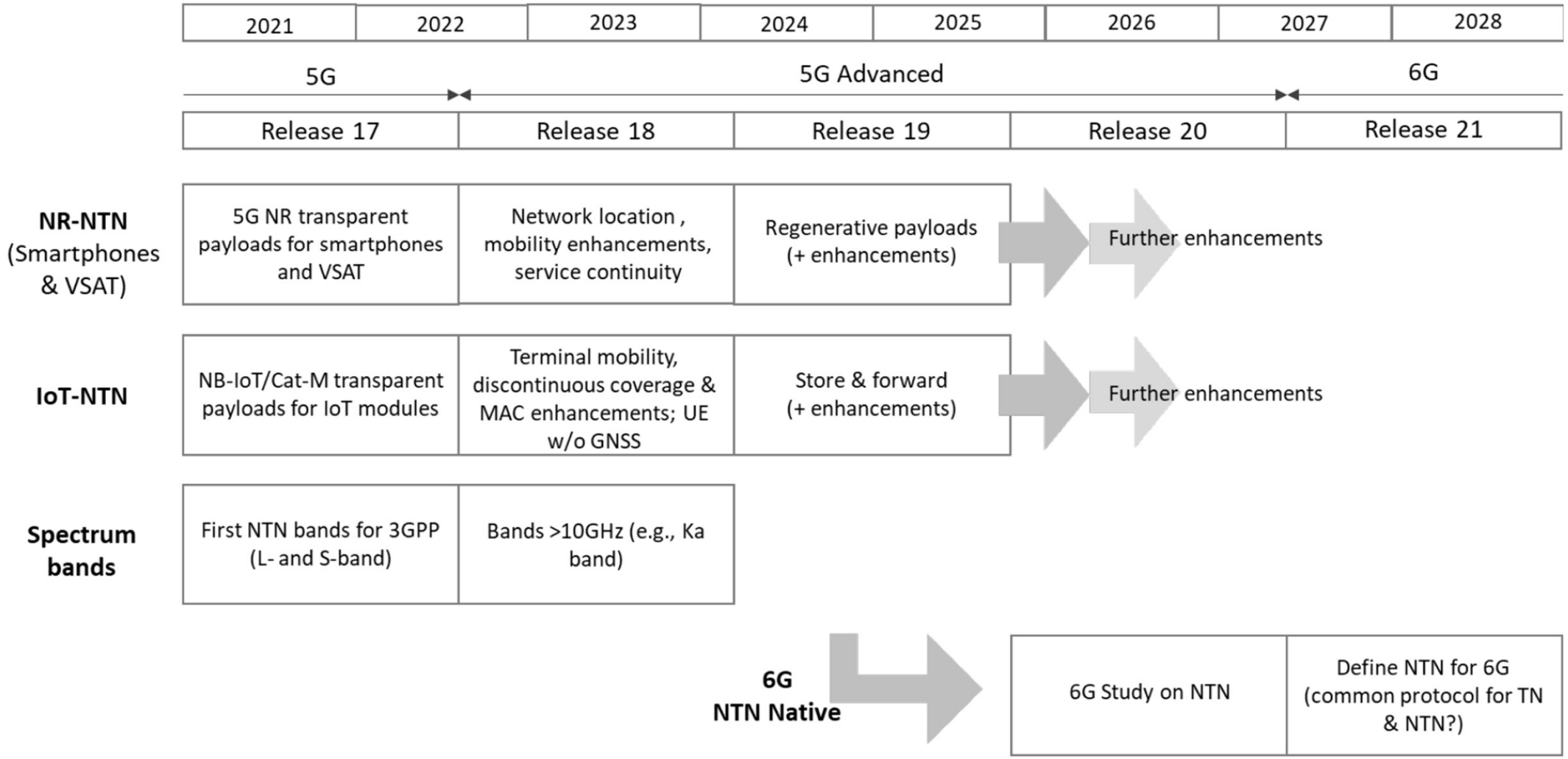
- Tranasparent and Regenerative





3GPP Releses

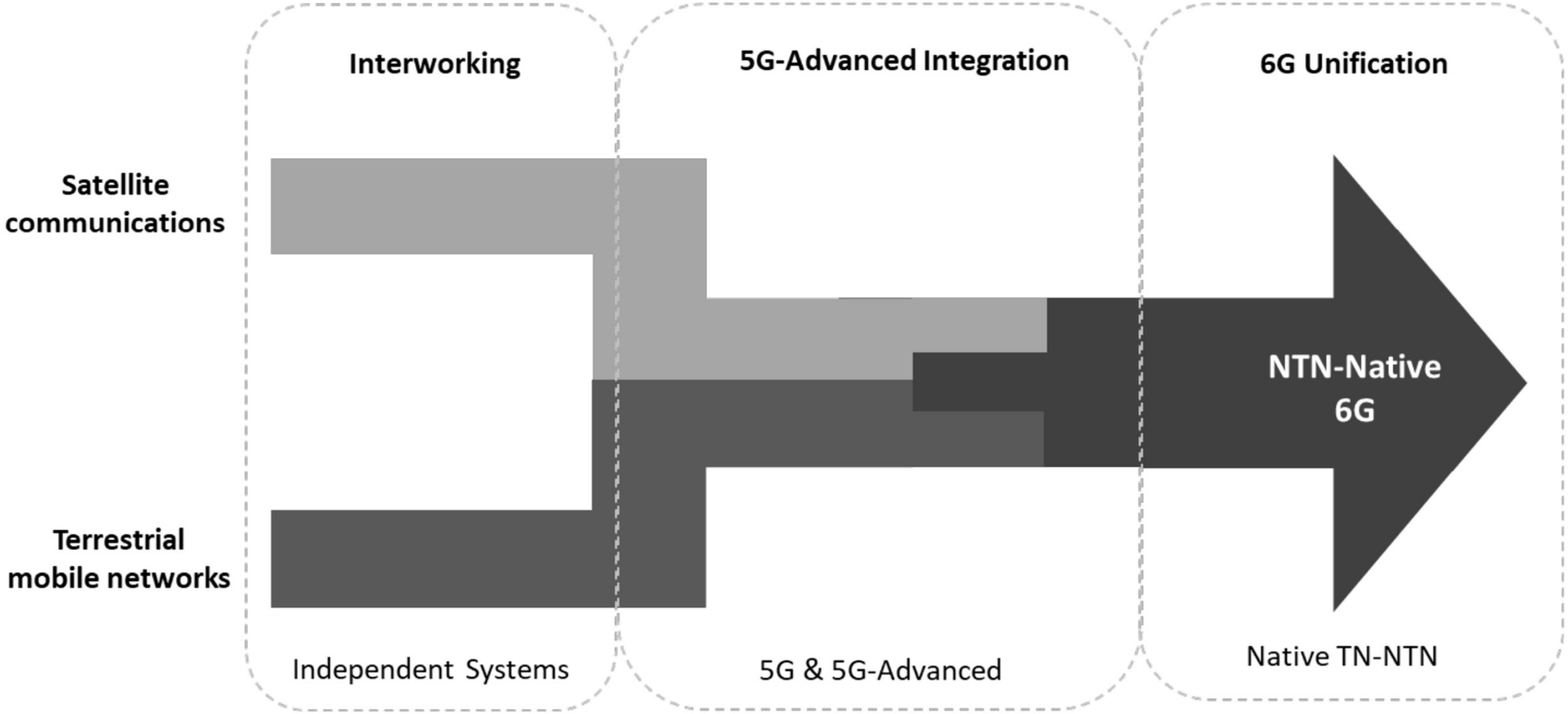
https://lr-resources.lightreading.com/?p=w_quam141&w=d&email=70bcaeea1dabc1c2fb343822772989df&key=WRtAXXJKZ3xtrj7587UH&ts=37516&u=086059175095171372064 7&e=Y2lua2xlckB0bWl0LmJtZS5odQ==&secure=1&_afn=0



NTN-native 6G

https://lr-resources.lightreading.com/?p=w_quam141&w=d&email=70bcaeea1dabc1c2fb343822772989df&key=WRtAXXJKZ3xtrj7587UH&ts=37516&u=0860591750951713720647&e=Y2lua2xlckB0bWl0LmJtZS5odQ==&secure=1&_afn=0

- NTN-TN convergence



TN-NTN Converged NTN-native 6G

- Release 20 onward; i.e., from 2025
- incorporate aerial technologies, including
  - HAPS (ballones, UAVs, drones, and aircraft)

3GPP Release 17

- L-band (band n255)
- S-band (band n256)

  - In NTN FR1 (Frequency Range 1)
  - which spans 410 MHz to 7125 MHz
  - there are two key bands:
    - n255 (NTN 1.6 GHz) and
    - n256 (NTN 2 GHz)
    - These form the 5G NTN band offering for the L-band and S-band, which is existing satellite band terminology.

“Building out the Starlink broadband megaconstellation”

- May 8, 2024: “It was SpaceX's 47th orbital launch of 2024 already.”
- A Falcon 9 rocket topped with 23 Starlink craft…
- they will be deployed about 65 minutes after liftoff
- https://www.space.com/spacex-starlink-launch-group-6-56

„Starlink Satellites Make Up 60% of All Active Spacecraft in Orbit”

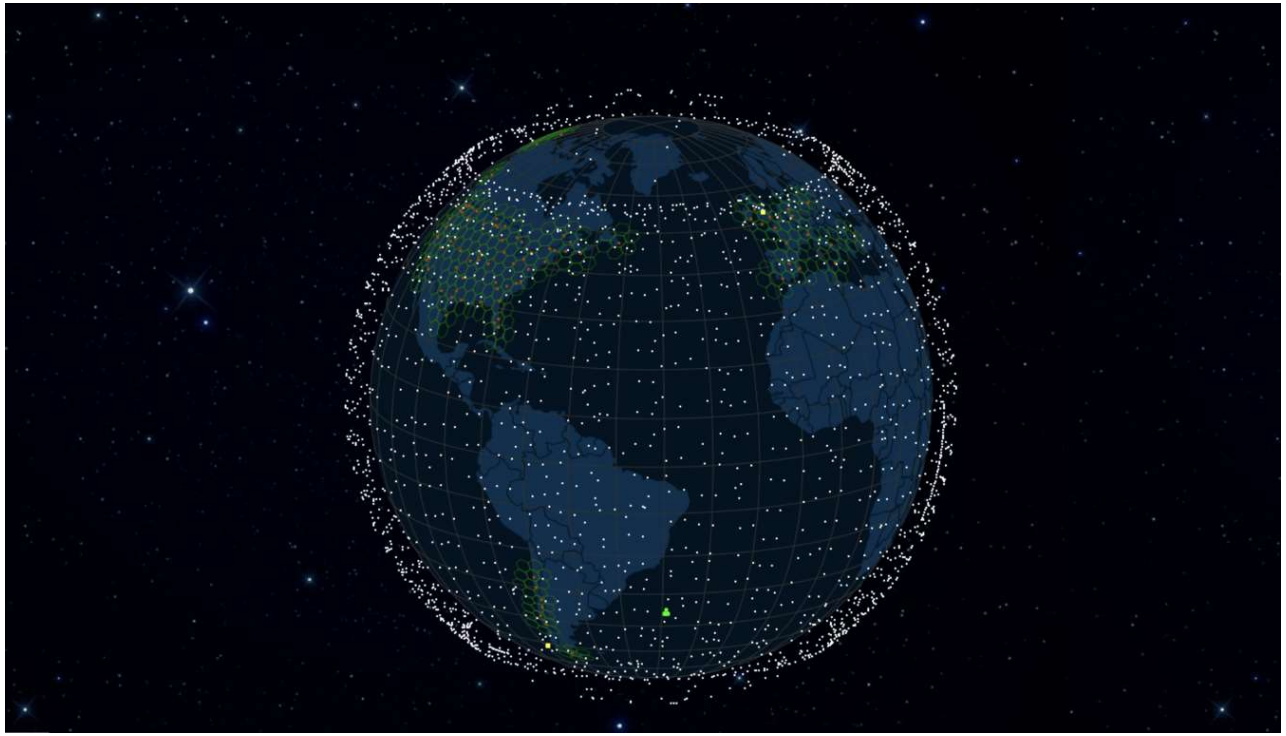
- https://www.pcmag.com/news/starlink-satellites-make-up-60-percent-active-spacecraft-in-orbit (May 2, 2024)
- „SpaceX now has nearly 5,900 Starlink satellites in low-Earth orbit, but it wants 30,000”
- Approximately 89% of orbiting satellites now belong to commercial firms as opposed to government or military groups; last year, 5,648 of the 9,241 active satellites were from Starlink.

“SpaceX Offers Starlink Hardware for $1 Through New Trial Offer”

- https://www.pcmag.com/news/spacex-offers-starlink-hardware-for-1-through-new-trial-offer (April 29, 2024)
- “The company will only charge the full $599 hardware fee 30 days after a dish is first activated.”
- “SpaceX is trying to entice more users to try out Starlink with a new "$1 for 30 days" trial.”
- “$120-per-month service fee”

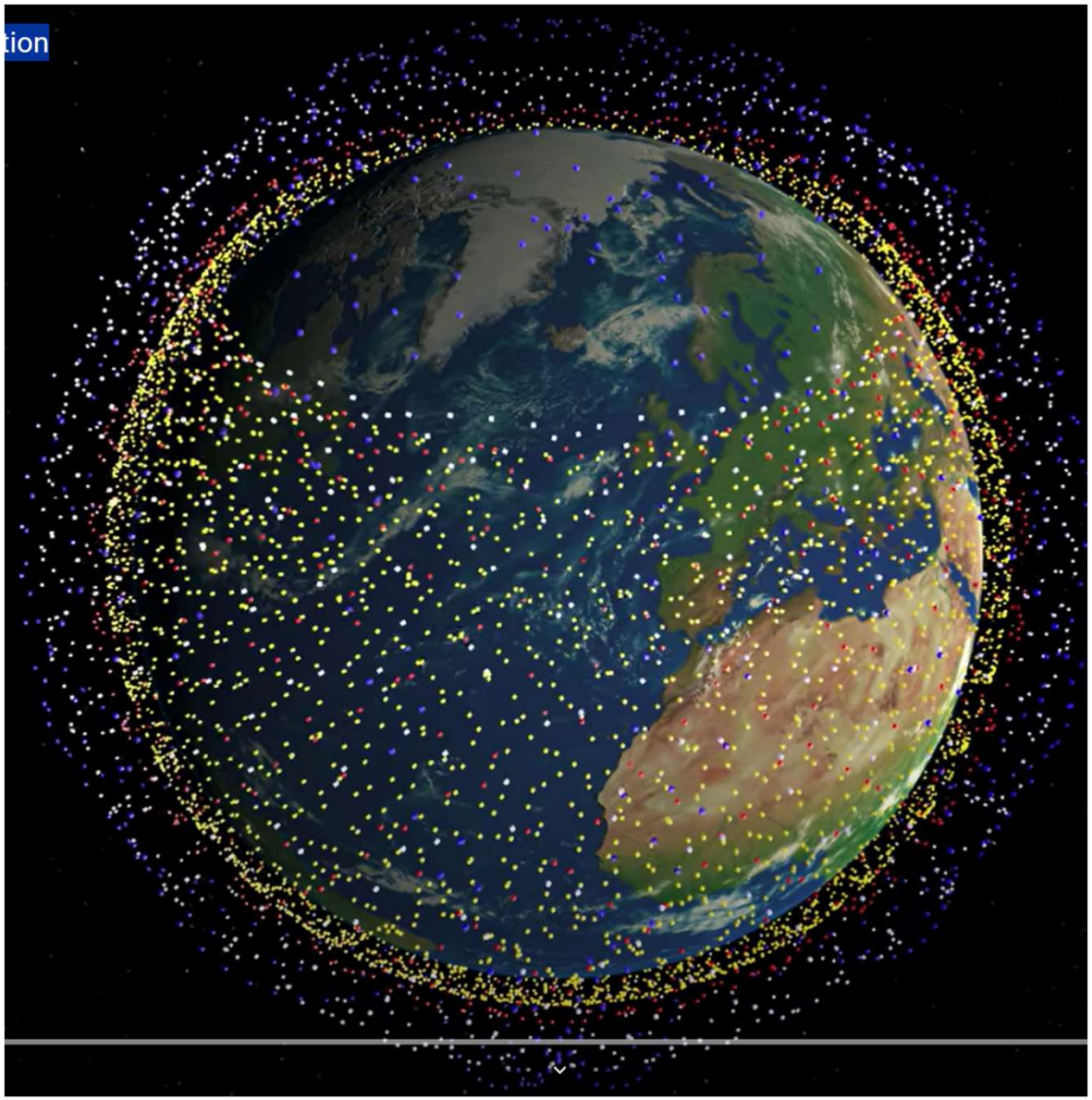
Collisions?

- “In the latter half of 2023, SpaceX told the FCC that Starlink satellites successfully avoided over 24,000 crashes with other objects in Earth's orbit”



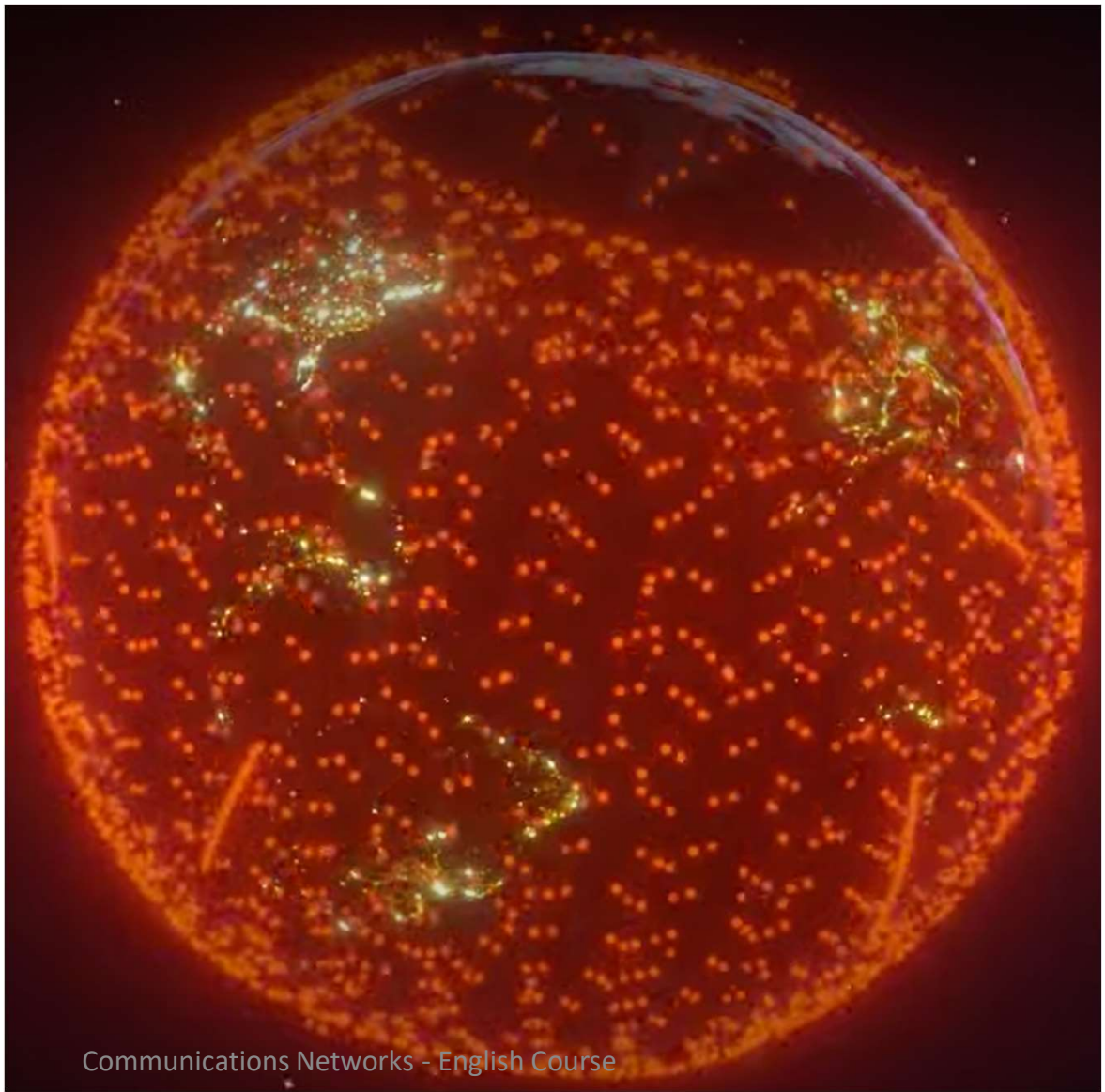
StarLink Constellation Animation

https://www.youtube.com/watch?v=bKj4GDNhH0Q



“This simulation shows the orbits of all **11927** satellites in the final proposed Starlink constellation. Red satellites are the initial 1584 satellites at **550km** altitude. White are 1600 second phase satellites at **1110km** altitude and 53.8 degree inclination. Blue are 1225 satellites in polar orbits. Yellow shows the final 7518 satellites in **335km to 345km VLEO** orbits, with inclinations of 53, 48 and 42 degrees.”

- https://www.youtube.com/shorts/cyThDF-vI48?feature=share



“Galileo: World’s Most Precise Satellite Navigation System Expands” (May 4, 2024)

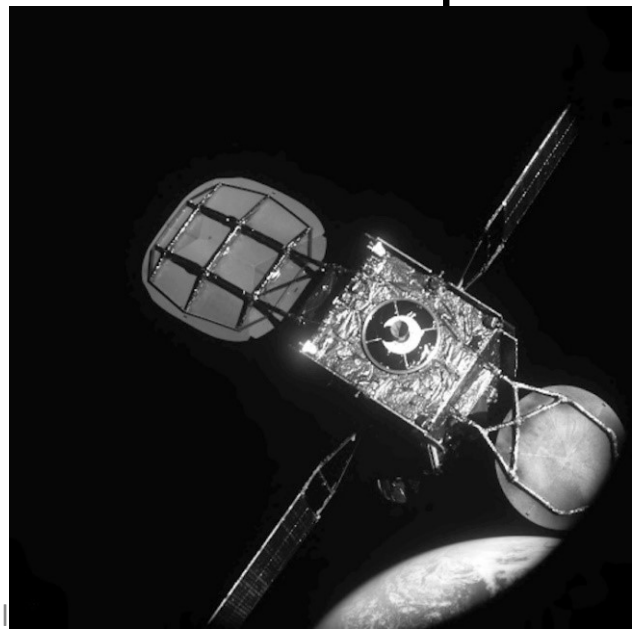
https://scitechdaily.com/galileo-worlds-most-precise-satellite-navigation-system-expands/

“The European Galileo navigation system has two more satellites in orbit following their launch in the early morning of Sunday, April 28. With 30 satellites now in orbit, Galileo is expanding its constellation, increasing the reliability, robustness and, ultimately, the precision, benefiting billions of users worldwide.”

“already 10% of the EU’s yearly GDP relies on satellite navigation and this is set to increase”

“Two giants in the satellite telecom industry join forces to counter Starlink”

- https://arstechnica.com/space/2024/04/the-two-largest-geostationary-satellite-operators-will-become-one/
- “Intelsat has 57 geostationary satellites, primarily for television and video-relay services.”
- “Founded in 1985, SES currently operates 43 geostationary satellites, plus 26 broadband spacecraft in medium-Earth orbit (MEO)”



EAN

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