NTNU – Trondheim
Norwegian University of
Science and Technology

Software-defined Intermittent Networking & H2020 MSCA IF

MarineUAS Winter School'18
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SINet

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Heterogeneous networking in challenging environments

Limited power and lossy networks
Software-defined and disruption-tolerant networking
Robust, hybrid and flexible networks

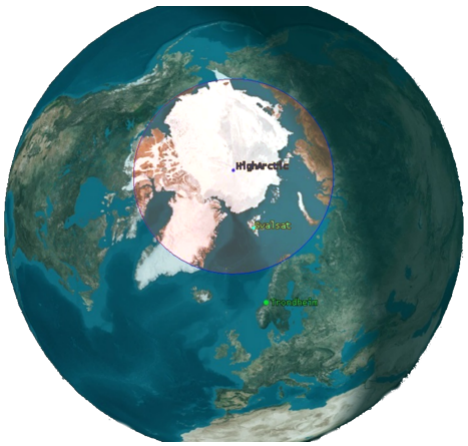
Internet of Arctic Things?

No communication backhaul

- Prolific research area
- Need for manned expeditions
- Limited satellite coverage

Harsh environment

- Extreme temperatures
- Hazardous
- Information deficit



Marie Skłodowska-Curie Actions – Individual Fellowship

MSCA IF

What is it?

"… (an opportunity for) enhancing the creative and innovative potential of Experienced Researchers who wish to diversify their individual competence in terms of skill acquisition through advanced training, international and intersectoral mobility…"

Why?

- For strengthening contact networks
- To catalyse the development of your career
- To improve and maximise the knowledge-based economy and society
- To improve working and living conditions
- For promoting mobility
- To open up new perspectives for research careers

How?

- Follow the calls in the EC Participant Portal
  - https://ec.europa.eu/research/participants/portal4/desktop/en/home.html
- Read the Guide for Applicants thoroughly
- Write a **clear** and ambitious research proposal
- Submit your proposal electronically

Main aspects

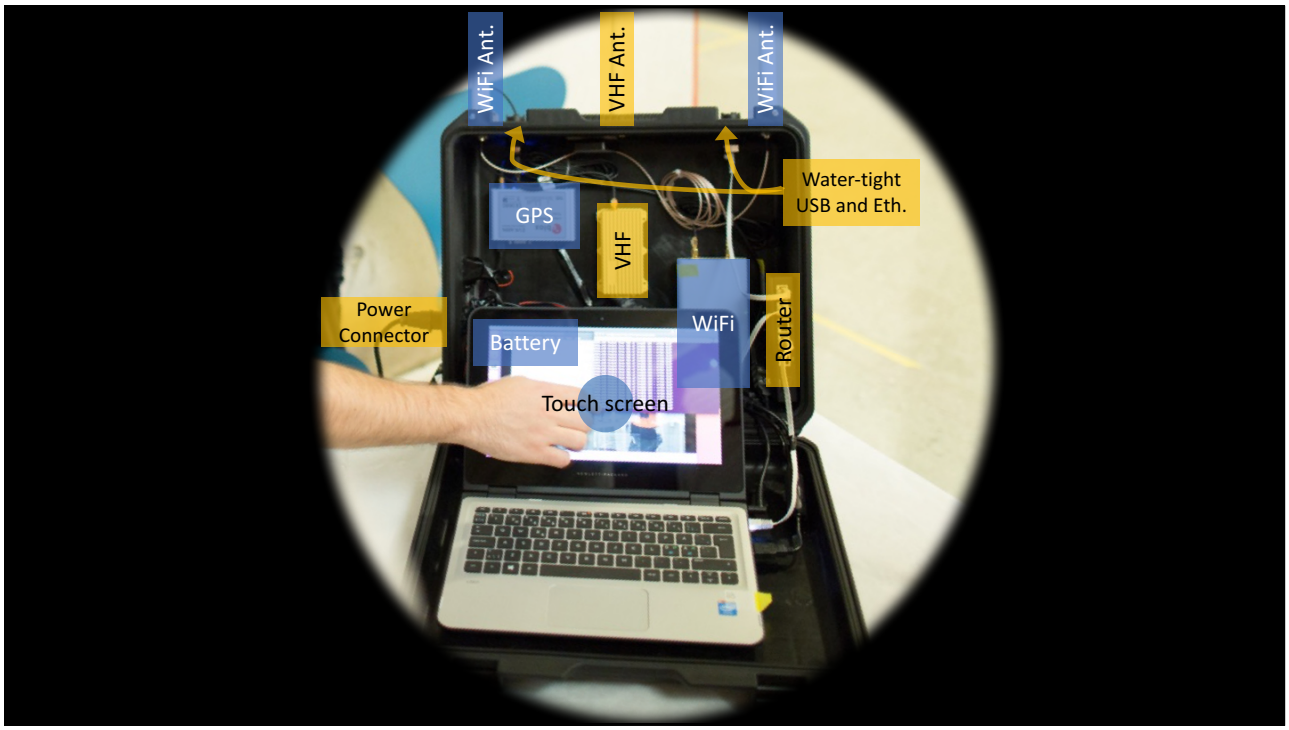
- Excellence
- Impact
- Implementation

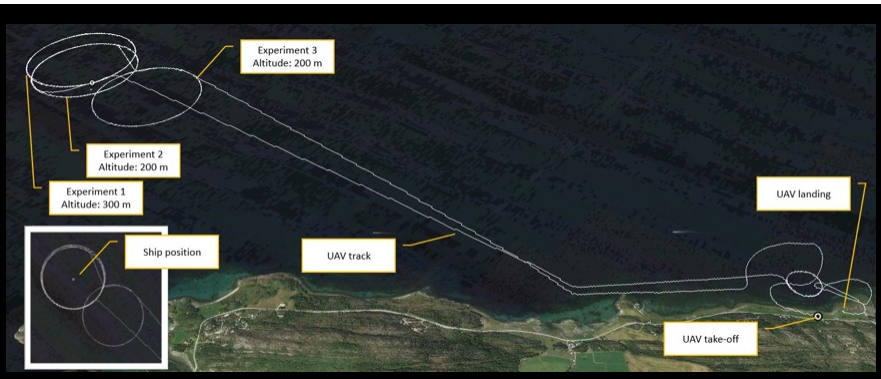
- Mobility
- 10-page limit (excluding CV)
- 12 to 24 months

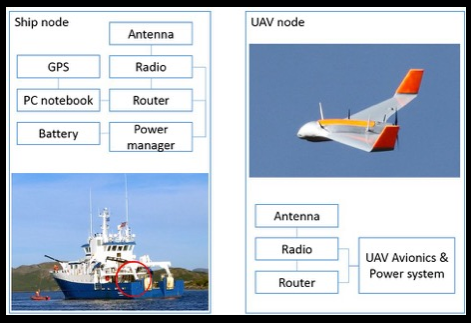
A few suggestions

- Take your time
- Plan and organise
- Follow the guidelines
- Review your own writing
- Contact your local EU advisors
- Be in touch with industry
- Use tables and figures
- Think as a reviewer

- Don't give up!


WiFi Ant.
VHF Ant.
WiFi Ant.
Water-tight
USB and Eth.
GPS
VHF
Power
Connector
Battery
WiFi
Router
Touch screen





Exp.	Maximum number of completed file transfers	Percentage of the best result			
		DTN	FTP	Rsync	SCP
Error factor x1 (EF_{x1})					
1	560	100%	100%	100%	100%
2	475	96%	93%	100%	98%
3	462	92%	91%	100%	95%
Error factor x2 (EF_{x2})					
1	352	100%	76%	97%	95%
2	179	100%	60%	75%	71%
3	180	100%	56%	56%	83%

D. Palma, A. Zolich, Y. Jiang and T. A. Johansen, "Unmanned Aerial Vehicles as Data Mules: An Experimental Assessment," in *IEEE Access*

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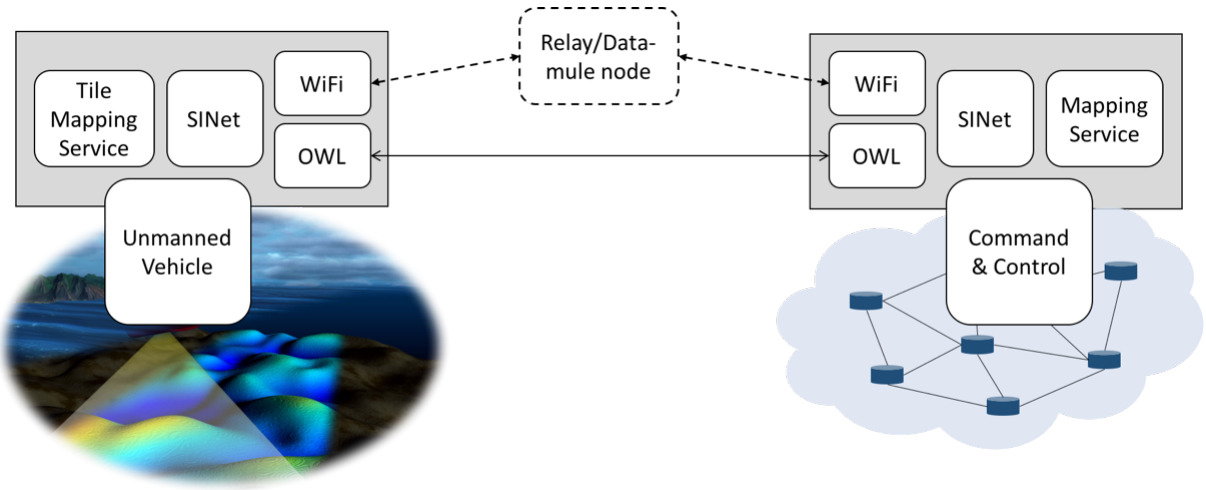
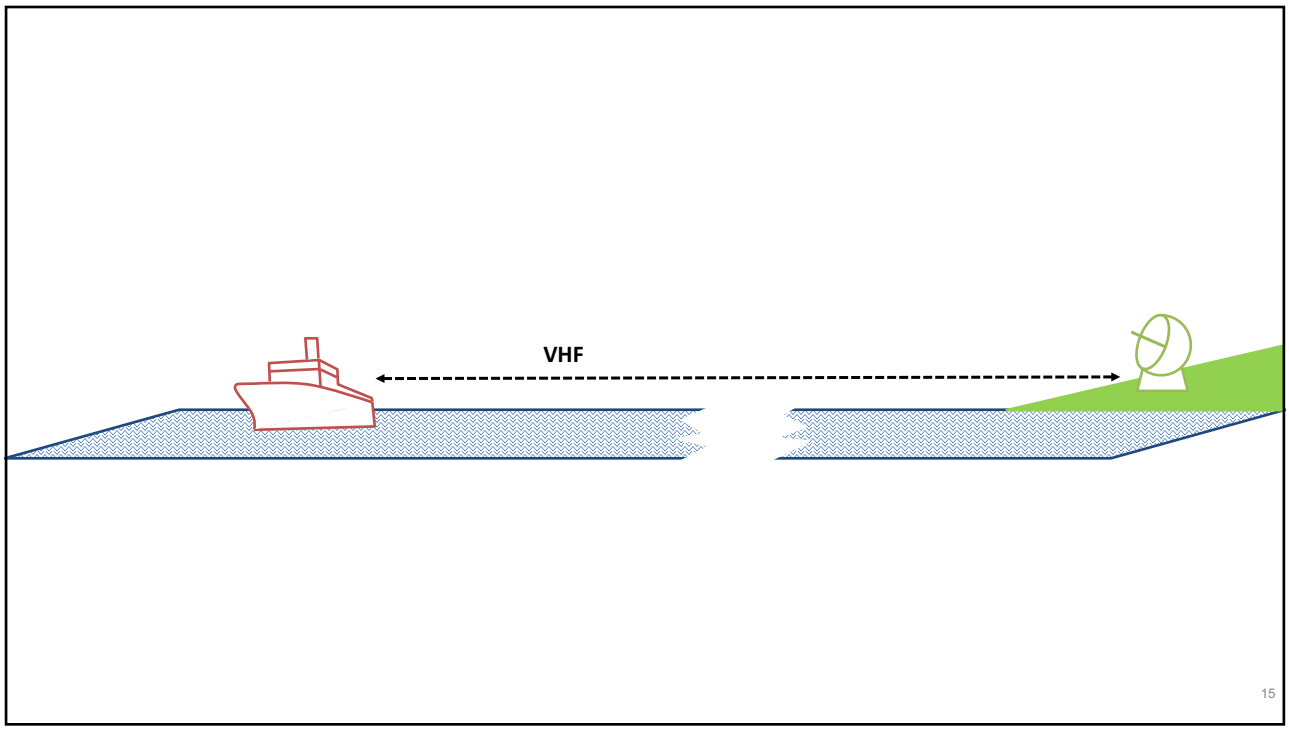
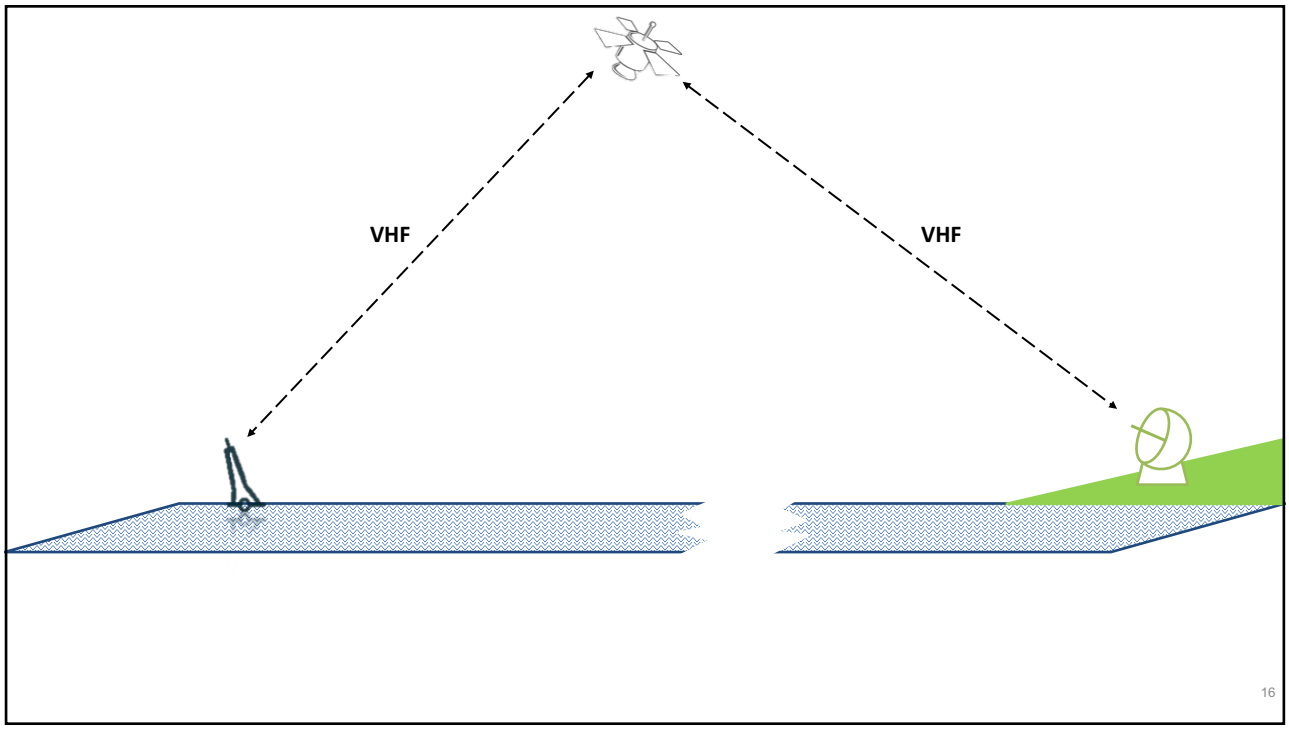
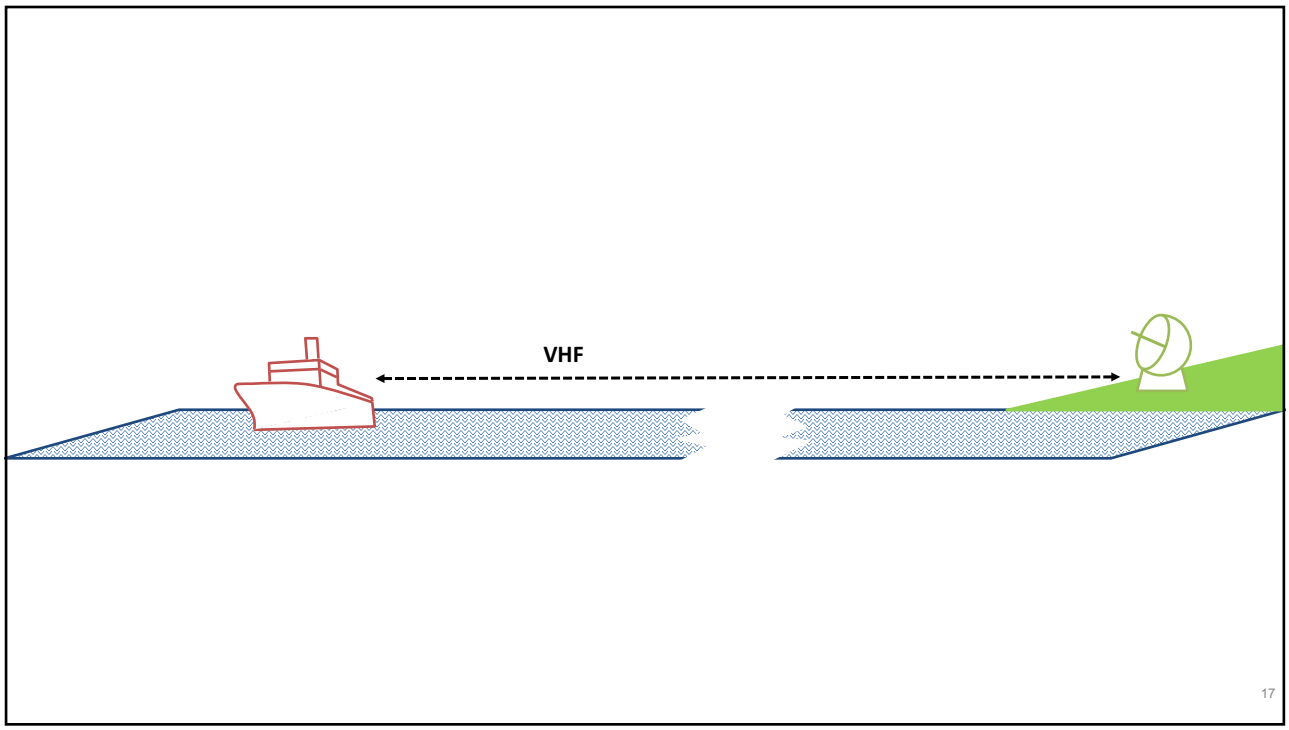
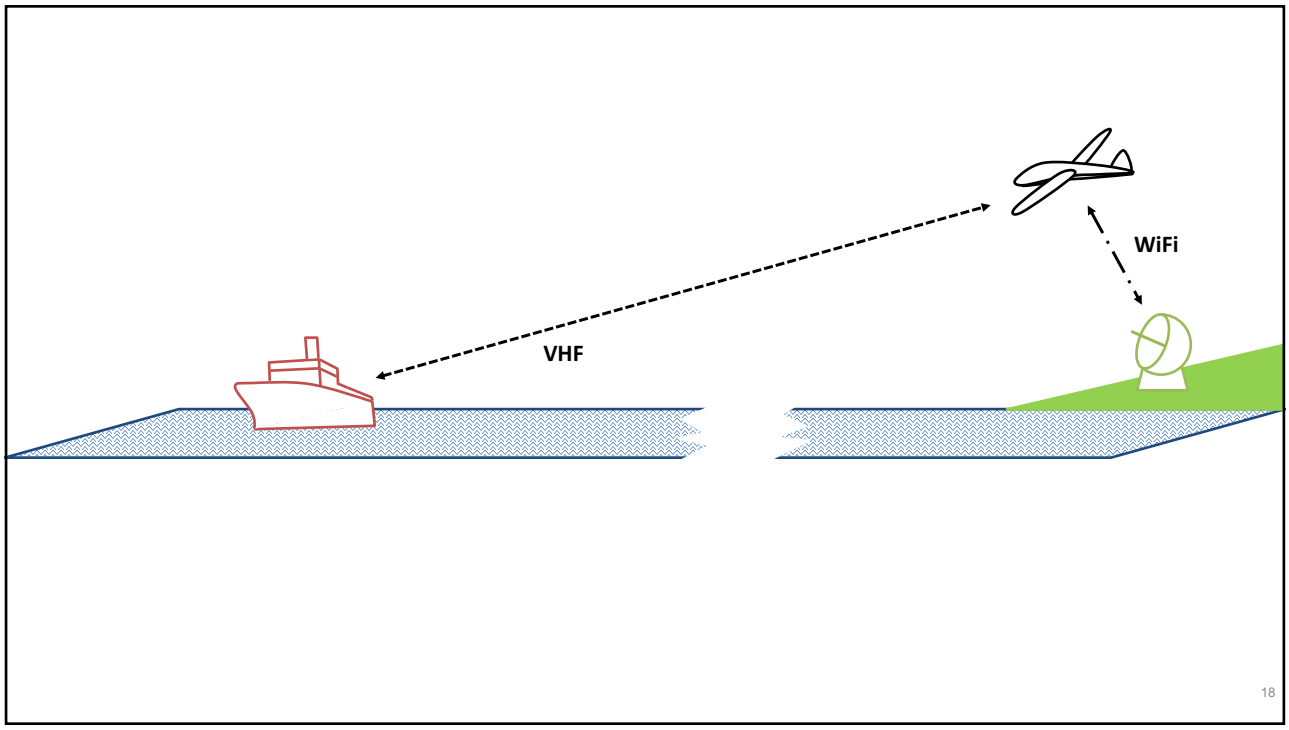


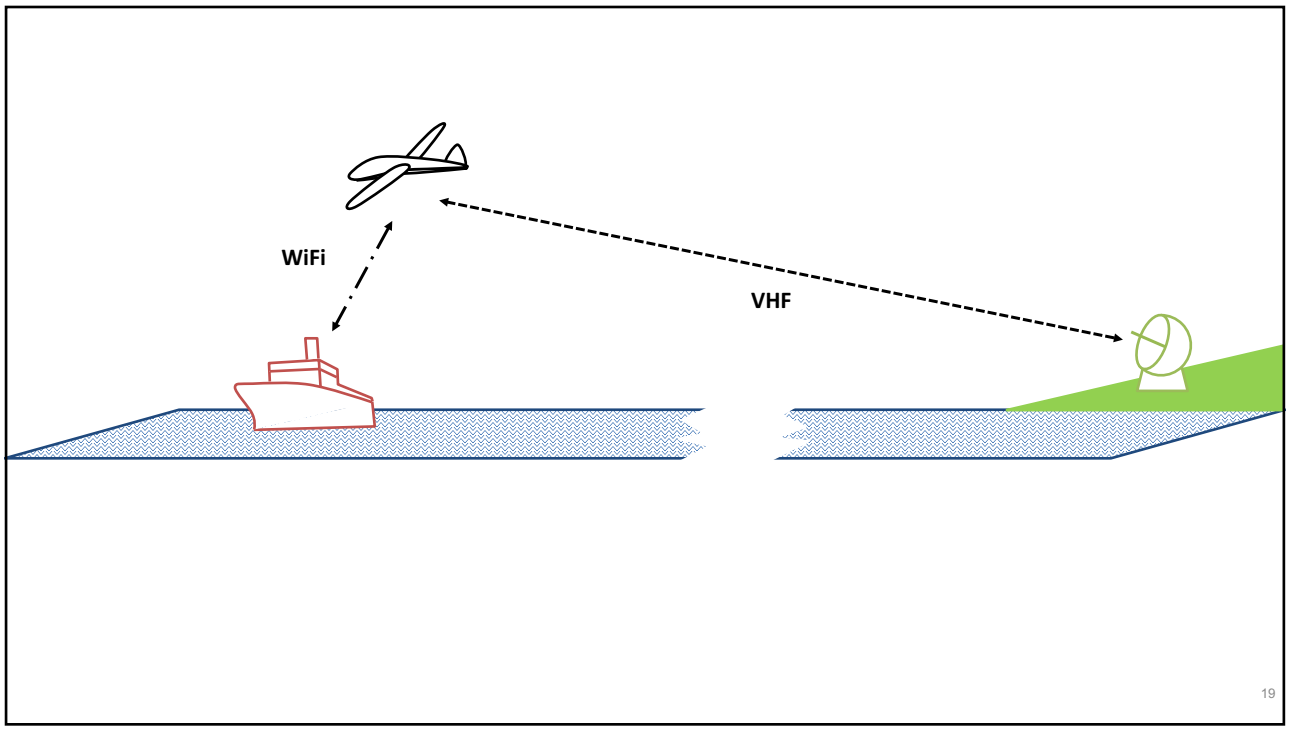
14

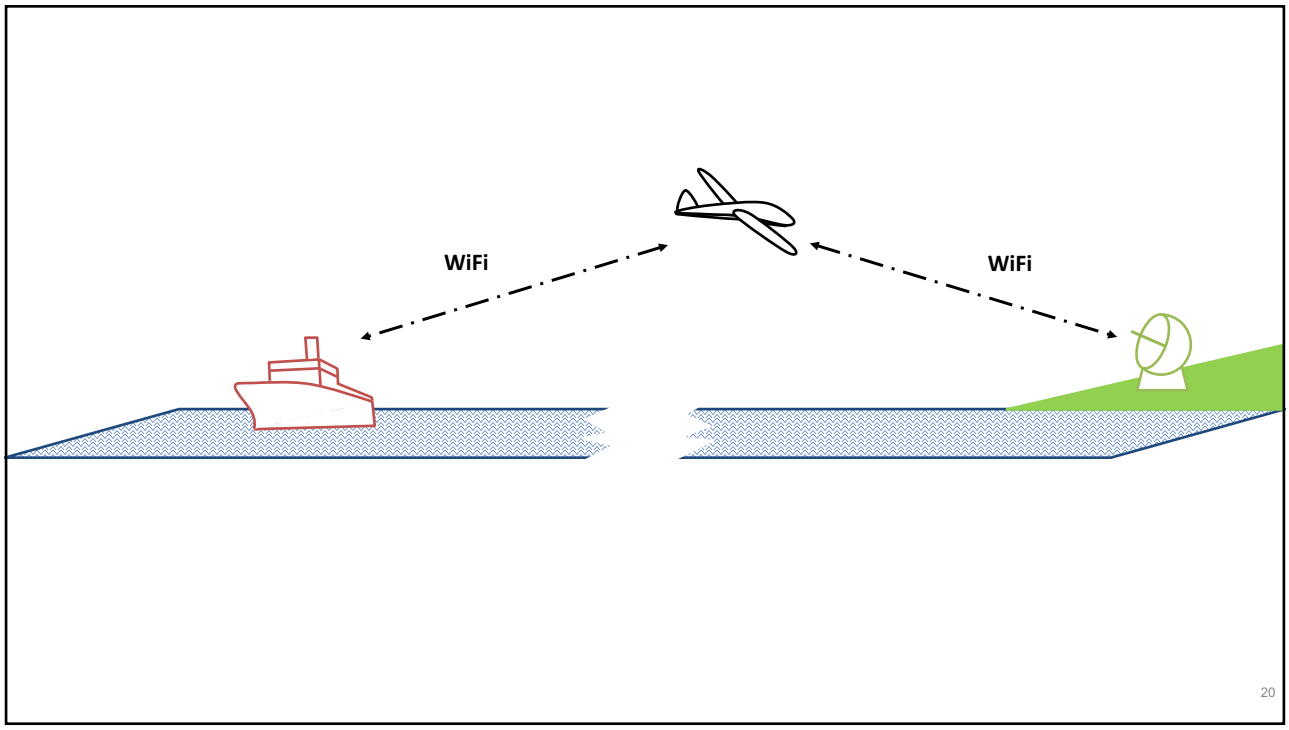

VHF
15

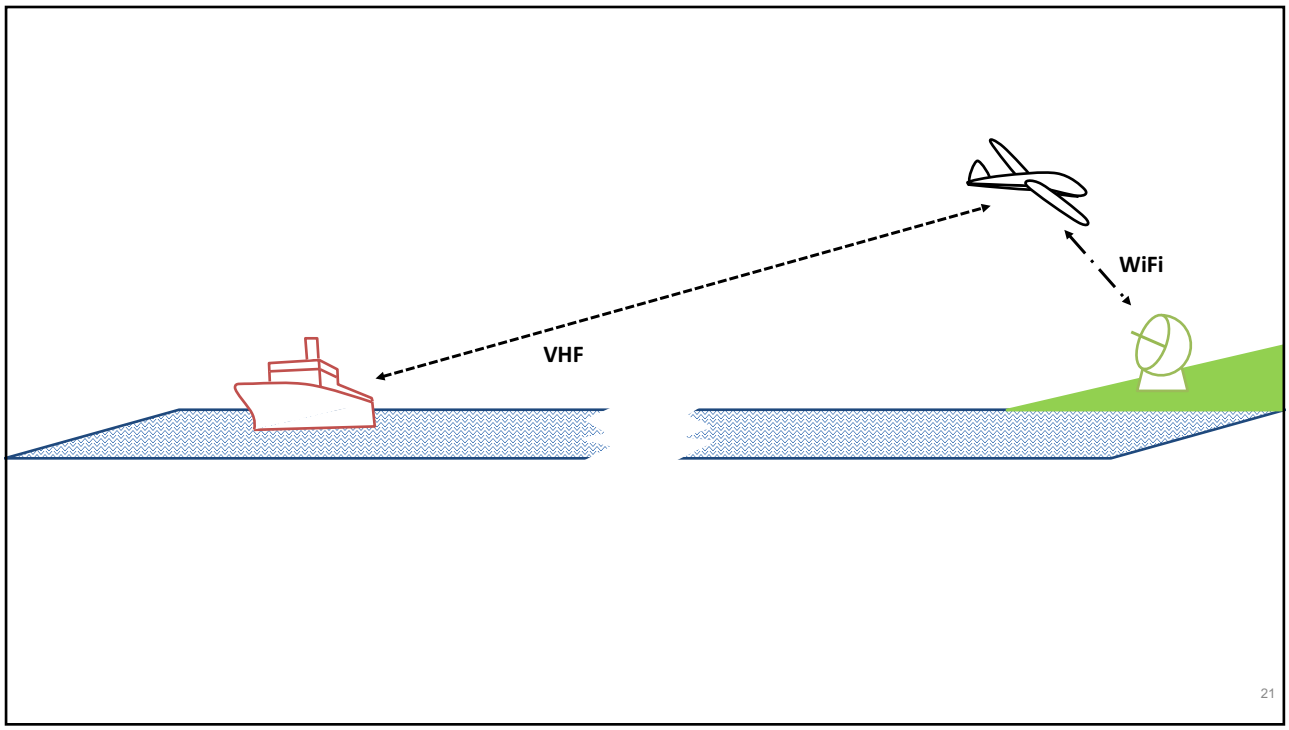

VHF
VHF
16

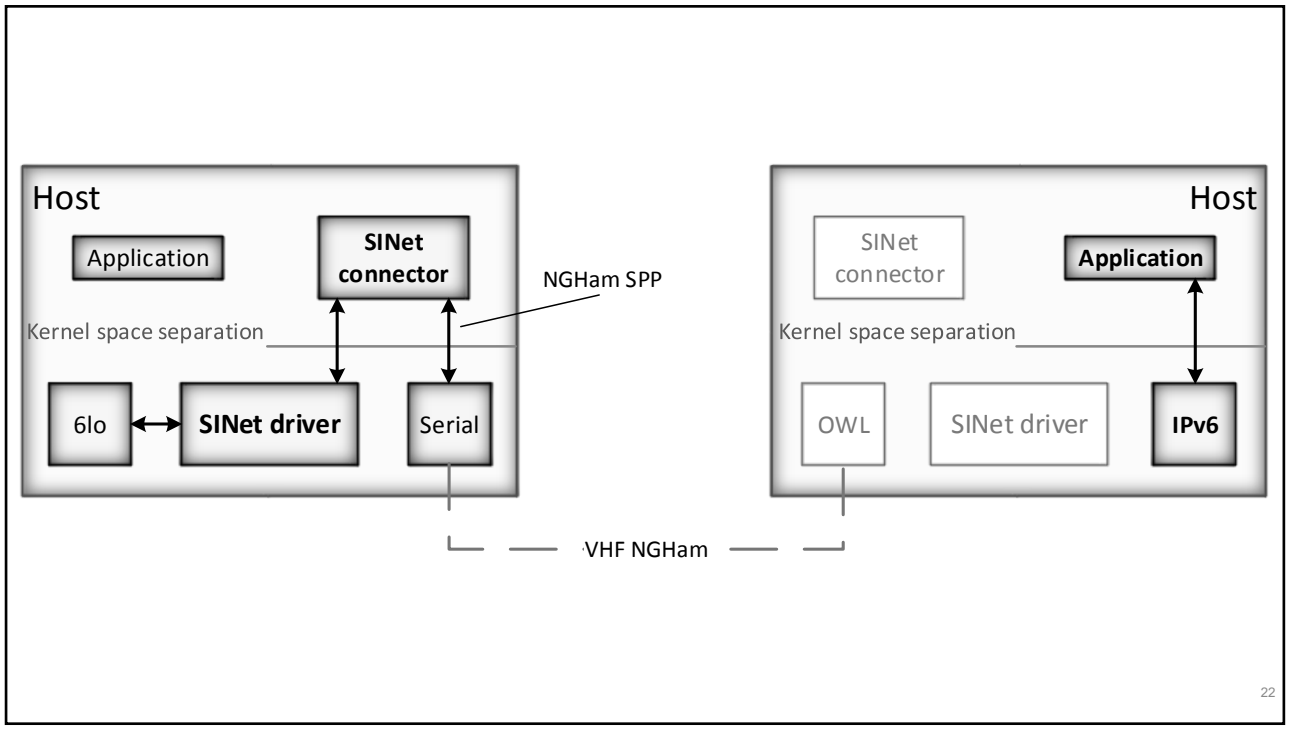

VHF
17


WiFi
VHF
18


WiFi
VHF
19


WiFi
WiFi
20


WiFi
VHF
21


Host
Application
SINet connector
NGHam SPP
Kernel space separation
6lo
SINet driver
Serial
Host
SINet connector
Application
Kernel space separation
OWL
SINet driver
IPv6
VHF NGHam
22

WPAN – Wireless Personal Area Network

- IEEE 802.15.1 – Bluetooth
- IEEE 802.15.4 – Low-Rate WPANs
  - Specification for the physical and data-link layers
  - Basis for several technologies
    - **6LoWPAN**
    - Thread
    - Zigbee
    - WirelessHART
- IEEE 802.15.6 – Body Area Networks
- IEEE 802.15.7 – Visible Light Communication

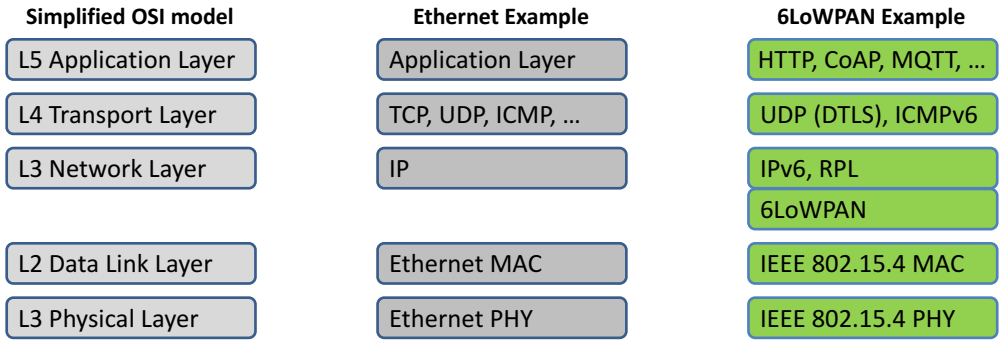
IEEE 802.15.4 – Specification for LR-WPANs

- Purpose:
  - ultra low complexity
  - ultra low cost
  - ultra low power consumption
  - low data rate wireless connectivity among inexpensive devices
- Main characteristics:
  - raw data rate of 250 kb/s
  - ability to scale down rate to 20 kb/s or below
  - PSDU of 127 octets (*aMaxPHYPacketSize*)
  - defined for multiple PHYs (various frequency bands)
  - link-layer security

6LoWPAN – IPv6 over Low-Power Wireless Personal Area Networks

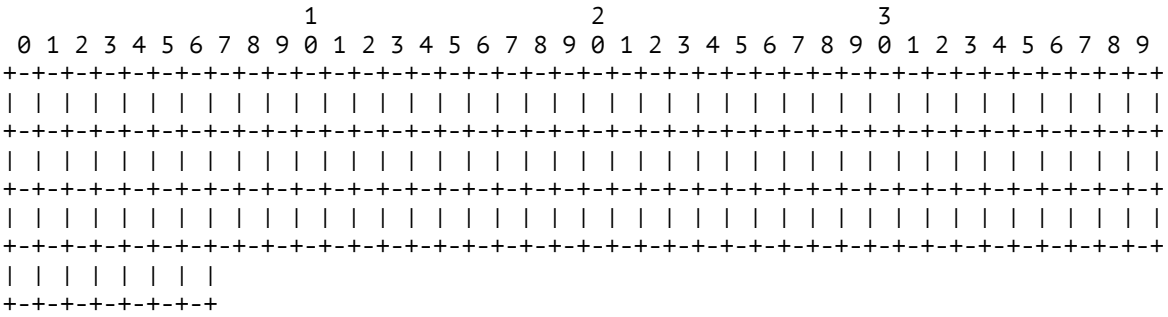
- IETF specifications for using IPv6 over IEEE 802.15.4 (LR-WPAN)
  - direct IPv6 addressing of embedded/constrained nodes
  - adaptation layer between data-link and network layer
  - frame encapsulation and fragmentation
  - header compression
  - neighbour discovery (ND)
  - address autoconfiguration
  - support for both 16-bit short or IEEE 64-bit addresses
  - …

6LoWPAN – Overview



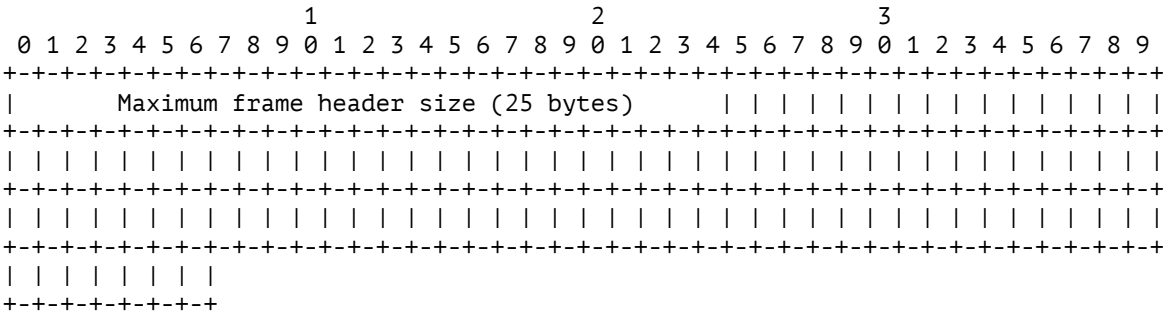
6LoWPAN – Frame Size Problem

- IEEE 802.15.4 defines a maximum frame size of 127 bytes



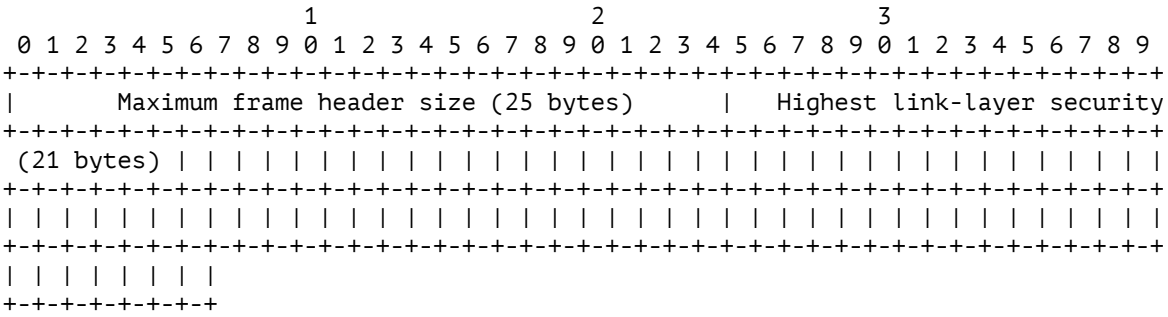
6LoWPAN – Frame Size Problem

- IEEE 802.15.4 defines a maximum frame size of 127 bytes
  - 102 bytes left



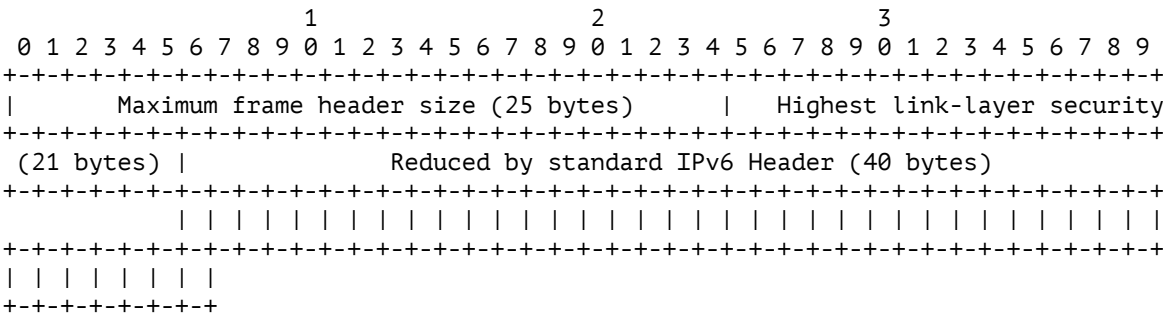
6LoWPAN – Frame Size Problem

- IEEE 802.15.4 defines a maximum frame size of 127 bytes
  - 81 bytes left



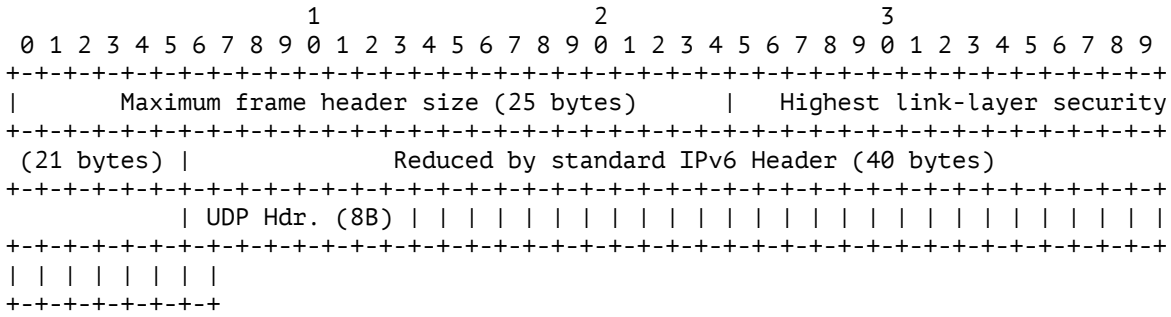
6LoWPAN – Frame Size Problem

- IEEE 802.15.4 defines a maximum frame size of 127 bytes
  - 41 bytes left



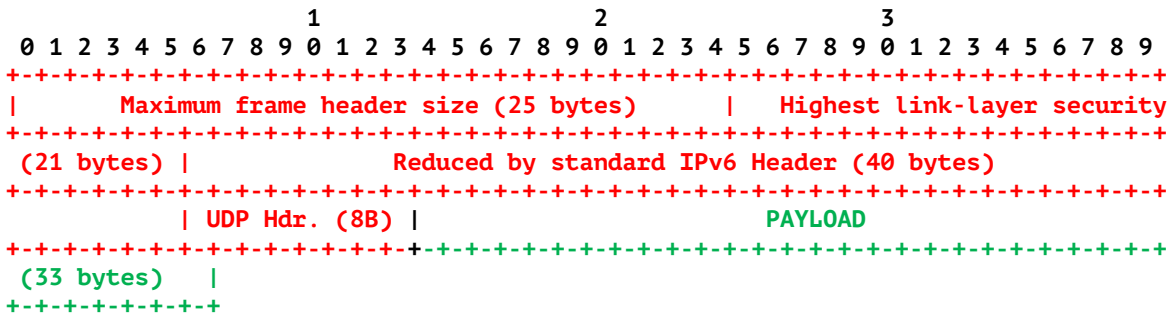
6LoWPAN – Frame Size Problem

- IEEE 802.15.4 defines a maximum frame size of 127 bytes
  - 33 bytes left



6LoWPAN – Frame Size Problem

- IEEE 802.15.4 defines a maximum frame size of 127 bytes
  - ≅3:1 ratio (75% overhead)

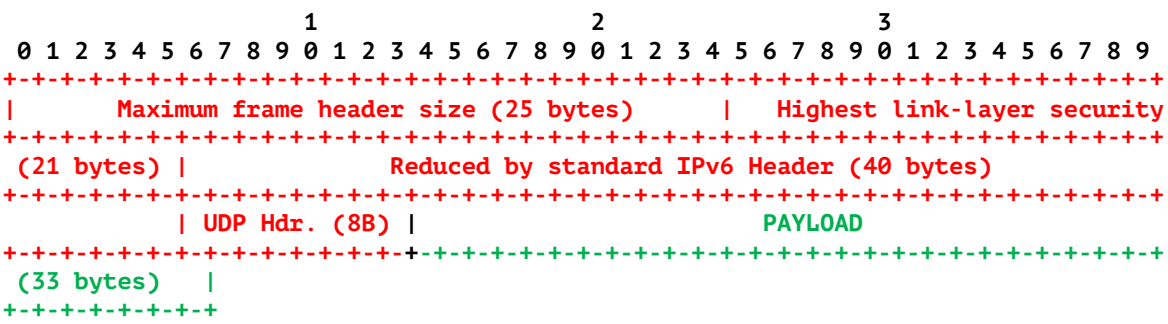


6LoWPAN – Header Compression

- Elision of unnecessary/redundant information
- Stateless compression
  - IP Header Compression (IPHC or HC1)
    - for link-local IPv6 headers
    - max. compression from 40 to 2 bytes
  - Next Header Compression (NHC or HC2)
    - for UDP headers
    - max. compression from 8 to 4 bytes
- Context-based compression
  - Context established when joining a 6LoWPAN network
  - Compression of global addresses, hop limit, ...

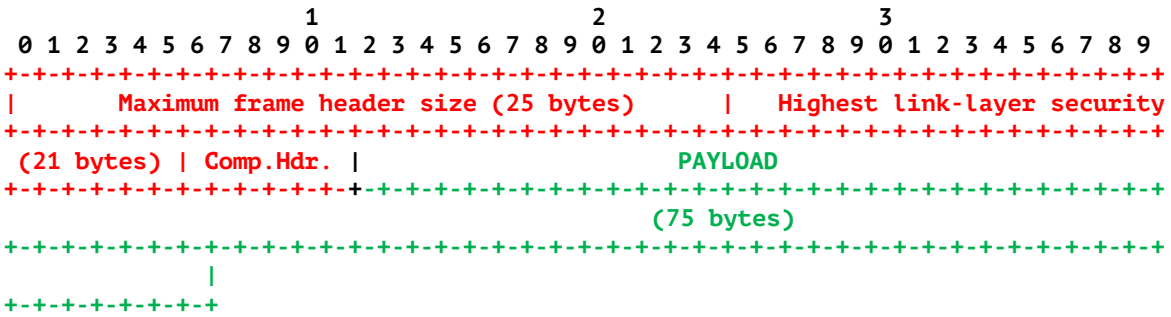
6LoWPAN – Frame Size Problem

- ≅3:1 ratio (75% overhead)



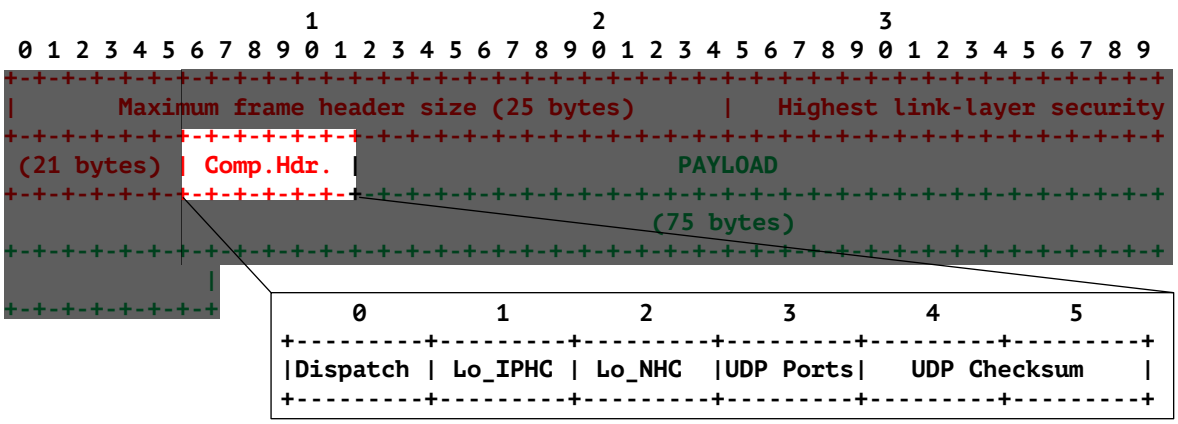
6LoWPAN – Frame Size Solution

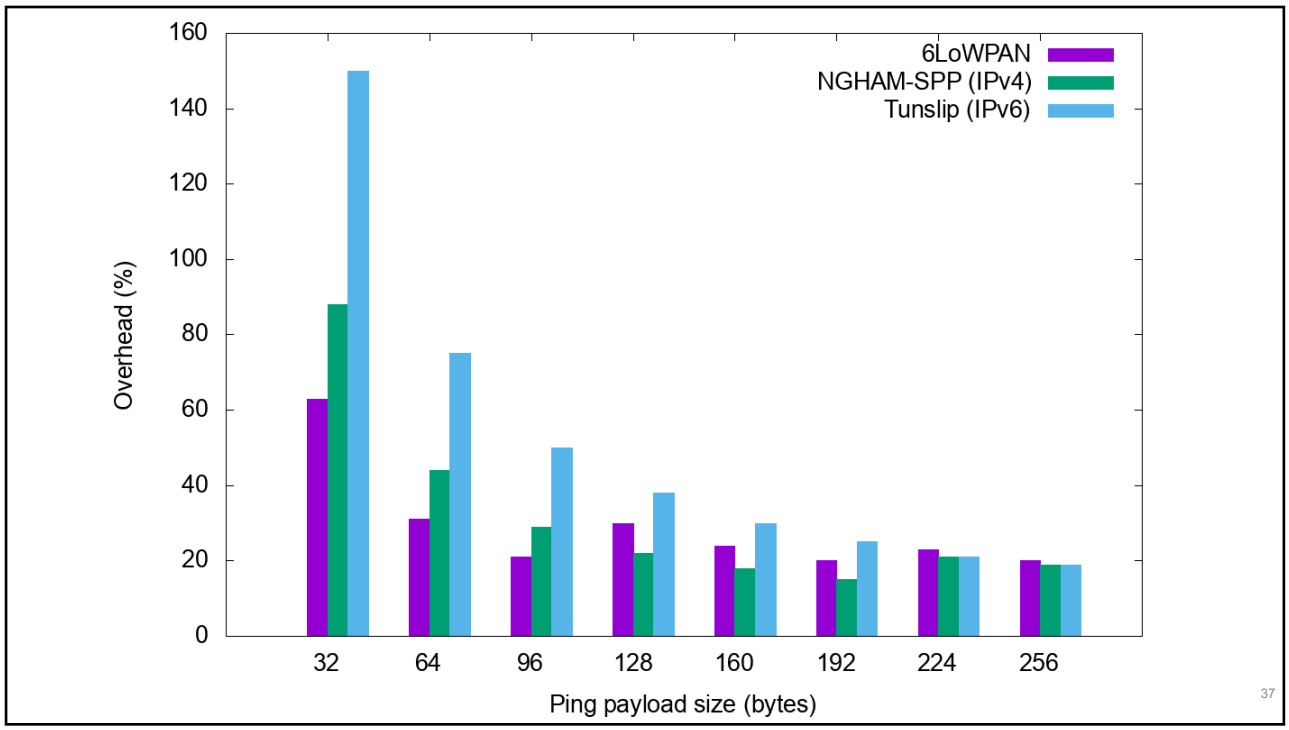
- 75 bytes payload (≅2:3 ratio, 20% overhead)

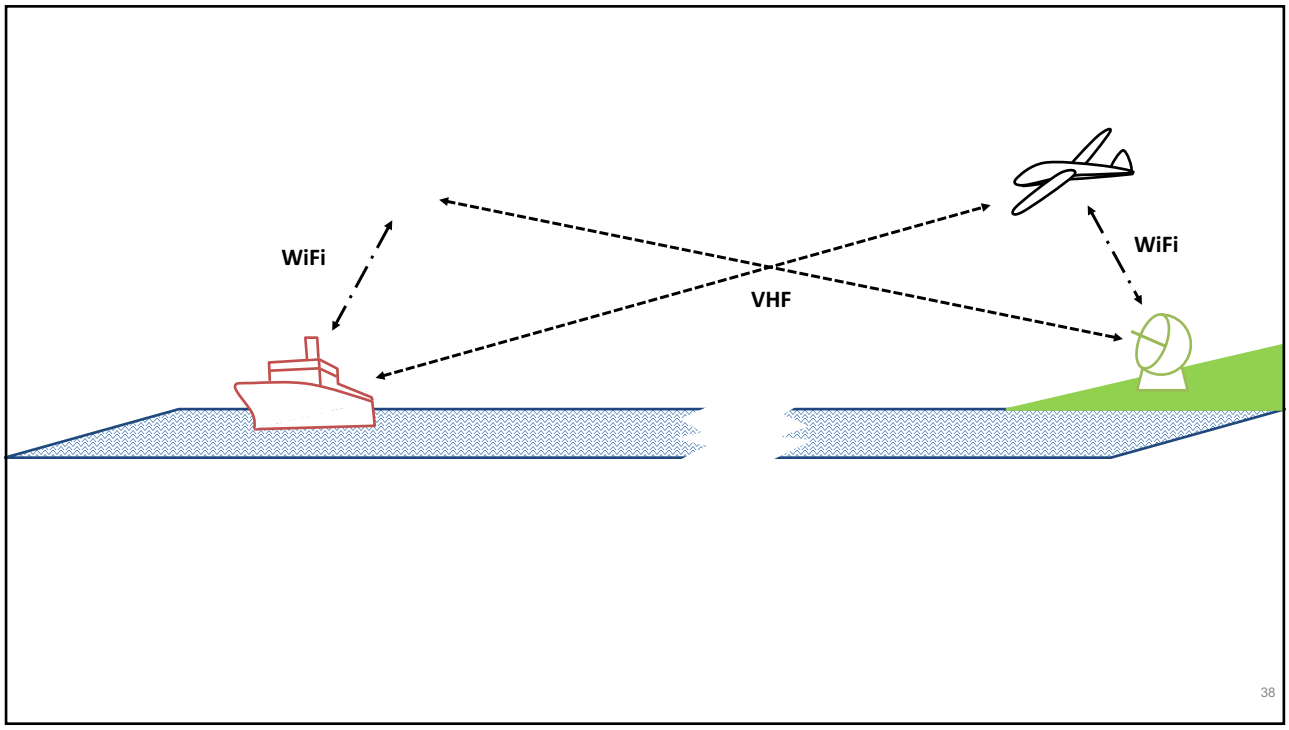


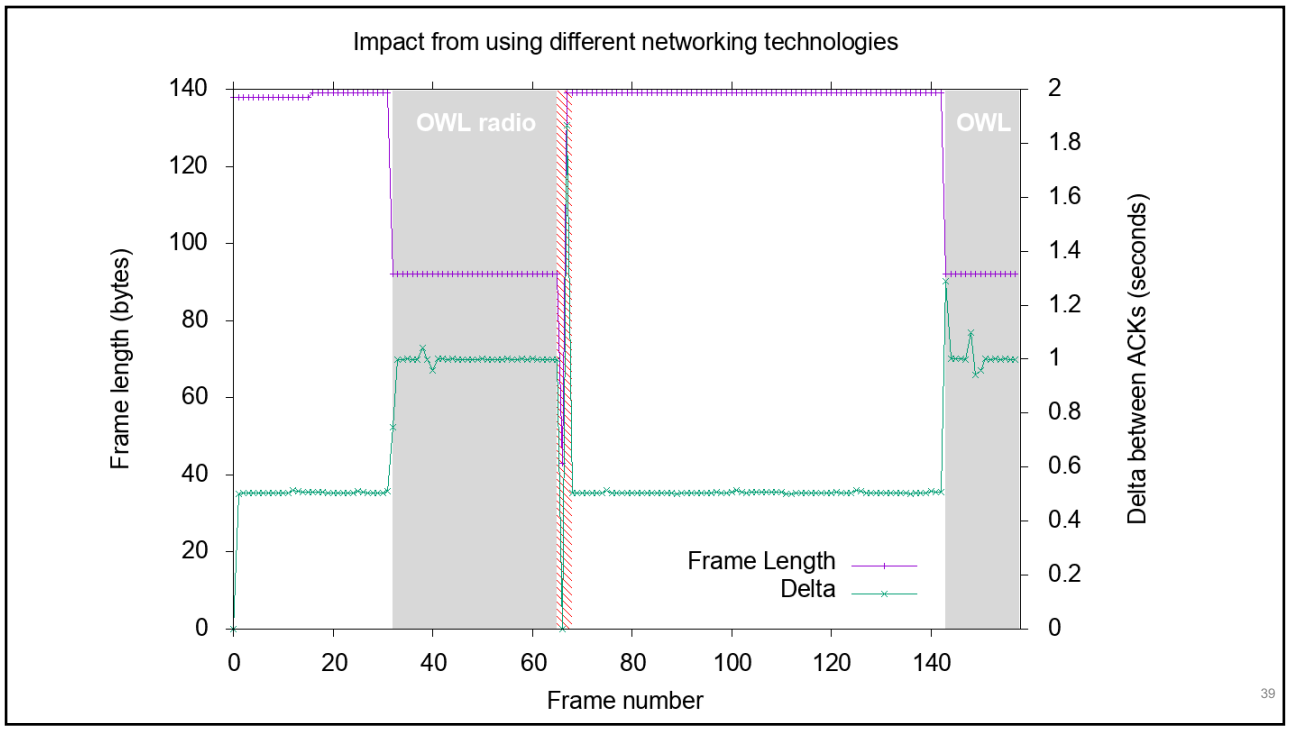
6LoWPAN – Frame Size Solution

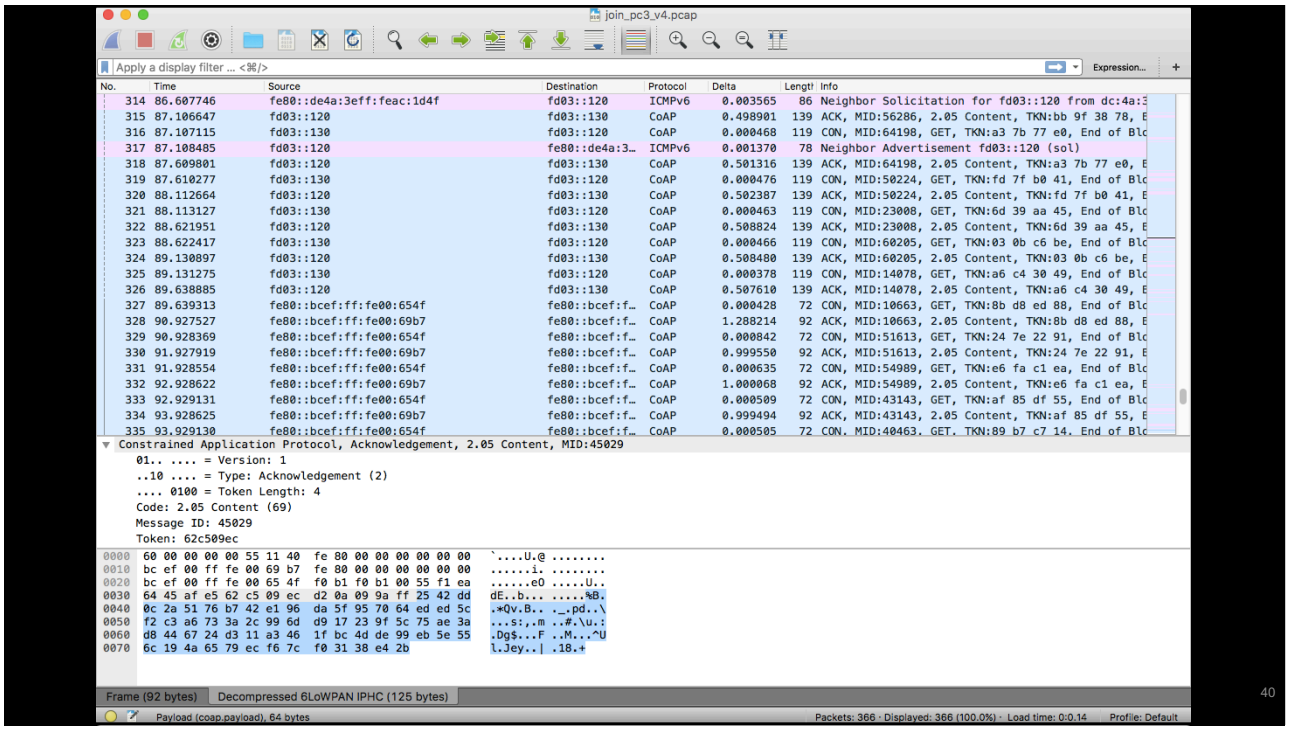
- 75 bytes payload (≅2:3 ratio, 20% overhead)




160
140
120
100
80
60
40
20
0
Overhead (%)
6LoWPAN
NGHAM-SPP (IPv4)
Tunslip (IPv6)
32
64
96
128
160
192
224
256
Ping payload size (bytes)
37


WiFi
VHF
WiFi
38

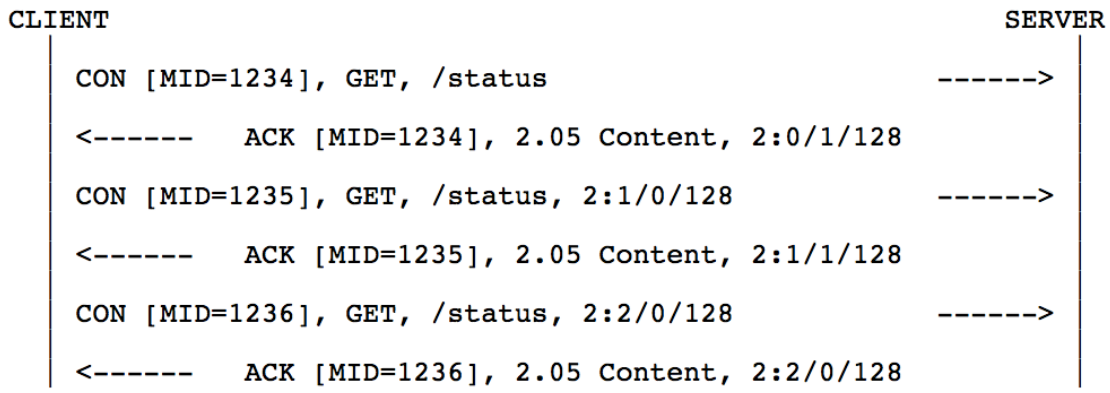

Impact from using different networking technologies
OWL radio
OWL
Frame length (bytes)
Delta between ACKs (seconds)
Frame Length
Delta
Frame number
0
20
40
60
80
100
120
140
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
39

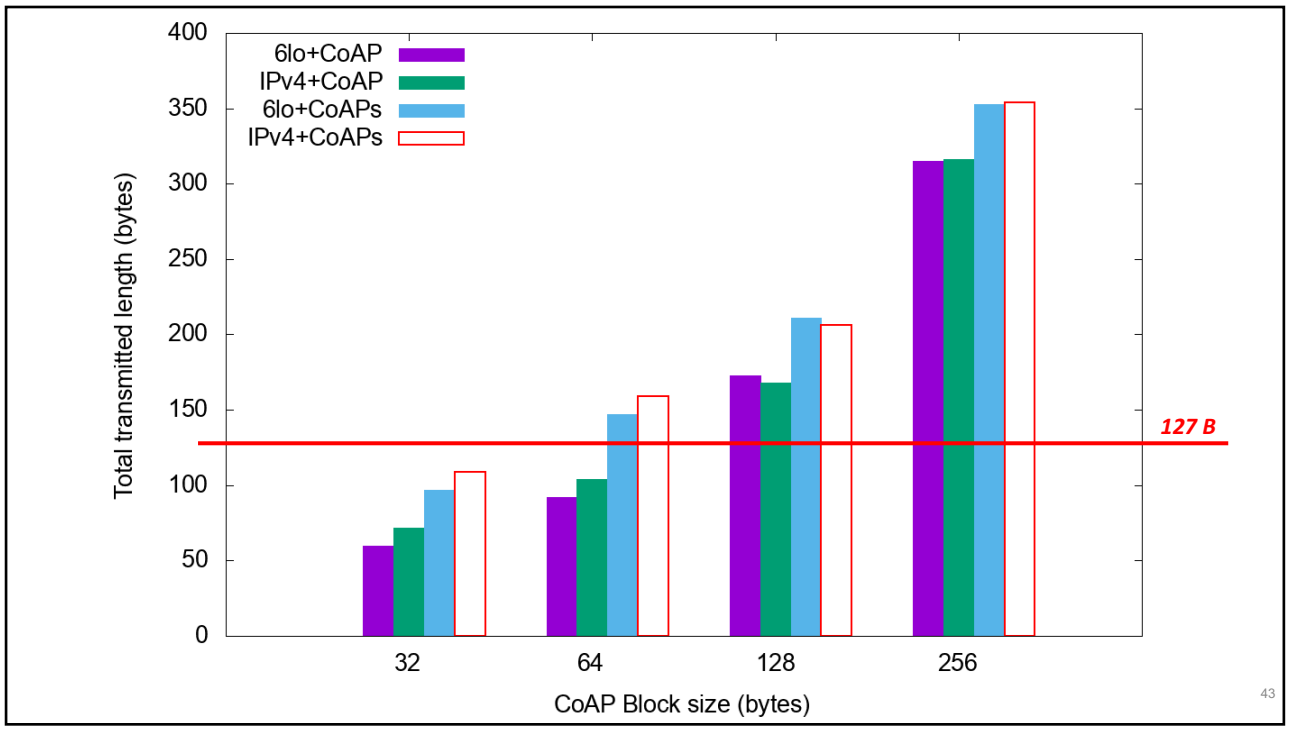

join_pc3_v4.pcap
Apply a display filter ... <⌘/>
Expression...
No. Time Source Destination Protocol Delta Length Info
314 86.607746 fe80::de4a:3eff:feac:1d4f fd03::120 ICMPv6 0.003565 86 Neighbor Solicitation for fd03::120 from dc:4a:3
315 87.106647 fd03::120 fd03::130 CoAP 0.498901 139 ACK, MID:56286, 2.05 Content, TKN:bb 9f 38 78, E
316 87.107115 fd03::130 fd03::120 CoAP 0.000468 119 CON, MID:64198, GET, TKN:a3 7b 77 e0, End of Blc
317 87.108485 fd03::120 fe80::de4a:3… ICMPv6 0.001370 78 Neighbor Advertisement fd03::120 (sol)
318 87.609801 fd03::120 fd03::130 CoAP 0.501316 139 ACK, MID:64198, 2.05 Content, TKN:a3 7b 77 e0, E
319 87.610277 fd03::130 fd03::120 CoAP 0.000476 119 CON, MID:50224, GET, TKN:fd 7f b0 41, End of Blc
320 88.112664 fd03::120 fd03::130 CoAP 0.502387 139 ACK, MID:50224, 2.05 Content, TKN:fd 7f b0 41, E
321 88.113127 fd03::130 fd03::120 CoAP 0.000463 119 CON, MID:23008, GET, TKN:6d 39 aa 45, End of Blc
322 88.621951 fd03::120 fd03::130 CoAP 0.508824 139 ACK, MID:23008, 2.05 Content, TKN:6d 39 aa 45, E
323 88.622417 fd03::130 fd03::120 CoAP 0.000466 119 CON, MID:60205, GET, TKN:03 0b c6 be, End of Blc
324 89.130897 fd03::120 fd03::130 CoAP 0.508480 139 ACK, MID:60205, 2.05 Content, TKN:03 0b c6 be, E
325 89.131275 fd03::130 fd03::120 CoAP 0.000378 119 CON, MID:14078, GET, TKN:a6 c4 30 49, End of Blc
326 89.638885 fd03::120 fd03::130 CoAP 0.507610 139 ACK, MID:14078, 2.05 Content, TKN:a6 c4 30 49, E
327 89.639313 fe80::bcef:ff:fe00:654f fe80::bcef:f… CoAP 0.000428 72 CON, MID:10663, GET, TKN:8b d8 ed 88, End of Blc
328 90.927527 fe80::bcef:ff:fe00:69b7 fe80::bcef:f… CoAP 1.288214 92 ACK, MID:10663, 2.05 Content, TKN:8b d8 ed 88, E
329 90.928369 fe80::bcef:ff:fe00:654f fe80::bcef:f… CoAP 0.000842 72 CON, MID:51613, GET, TKN:24 7e 22 91, End of Blc
330 91.927919 fe80::bcef:ff:fe00:69b7 fe80::bcef:f… CoAP 0.999550 92 ACK, MID:51613, 2.05 Content, TKN:24 7e 22 91, E
331 91.928554 fe80::bcef:ff:fe00:654f fe80::bcef:f… CoAP 0.000635 72 CON, MID:54989, GET, TKN:e6 fa c1 ea, End of Blc
332 92.928622 fe80::bcef:ff:fe00:69b7 fe80::bcef:f… CoAP 1.000068 92 ACK, MID:54989, 2.05 Content, TKN:e6 fa c1 ea, E
333 92.929131 fe80::bcef:ff:fe00:654f fe80::bcef:f… CoAP 0.000509 72 CON, MID:43143, GET, TKN:af 85 df 55, End of Blc
334 93.928625 fe80::bcef:ff:fe00:69b7 fe80::bcef:f… CoAP 0.999494 92 ACK, MID:43143, 2.05 Content, TKN:af 85 df 55, E
335 93.929130 fe80::bcef:ff:fe00:654f fe80::bcef:f… CoAP 0.000505 72 CON, MID:40463, GET, TKN:89 b7 c7 14, End of Blc
Constrained Application Protocol, Acknowledgement, 2.05 Content, MID:45029
01.. .... = Version: 1
..10 .... = Type: Acknowledgement (2)
.... 0100 = Token Length: 4
Code: 2.05 Content (69)
Message ID: 45029
Token: 62c509ec
0000 60 00 00 00 00 55 11 40 fe 80 00 00 00 00 00 00 `....U.@ ....
0010 bc ef 00 ff fe 00 69 b7 fe 80 00 00 00 00 00 00 ......i. ....
0020 bc ef 00 ff fe 00 65 4f f0 b1 f0 b1 00 55 f1 ea ......eO .....U..
0030 64 45 af e5 62 c5 09 ec d2 0a 09 9a ff 25 42 dd dE..b... .....%B.
0040 0c 2a 51 76 b7 42 e1 96 da 5f 95 70 64 ed ed 5c .*Qv.B.. ._.pd..\
0050 f2 c3 a6 73 3a 2c 99 6d d9 17 23 9f 5c 75 ae 3a ...s:,.m ..#.\u.:
0060 d8 44 67 24 d3 11 a3 46 1f bc 4d de 99 eb 5e 55 .Dg$...F ..M...^U
0070 6c 19 4a 65 79 ec f6 7c f0 31 38 e4 2b l.Jey..| .18.+
Frame (92 bytes)
Decompressed 6LoWPAN IPHC (125 bytes)
Payload (coap.payload), 64 bytes
Packets: 366 · Displayed: 366 (100.0%) · Load time: 0:0.14
Profile: Default
40

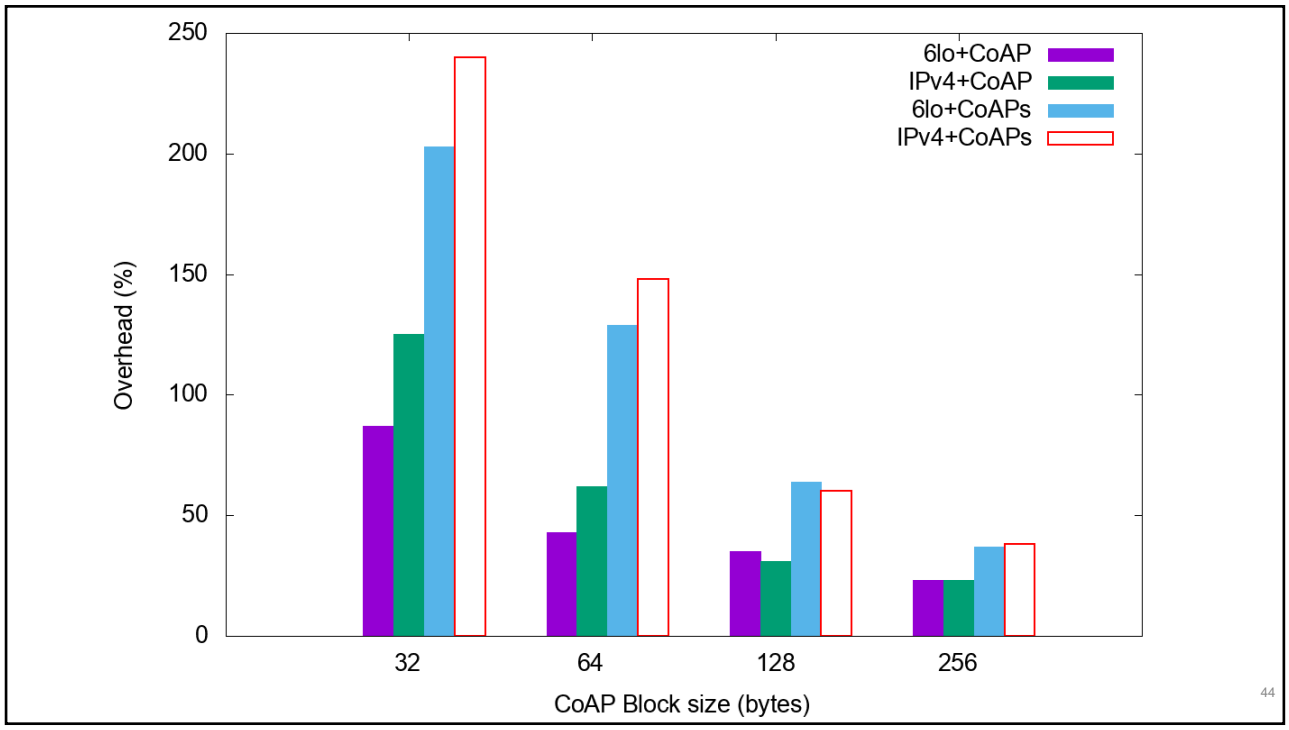
Constrained Application Protocol (CoAP)

	CoAP	HTTP
Protocol	UDP	TCP
Network layer	IP (considers 6LoWPAN too)	IP
Multicast support	Supported	Not supported
Architecture model	Client-Server & Publish-Subscribe	Client-server
Synchronous communication	Not required	Required
Payload Size	Fixed/Negotiable	Variable
Overhead	Low overhead and simple.	High overhead and complex

CoAP simple block-wise GET




6lo+CoAP
IPv4+CoAP
6lo+CoAPs
IPv4+CoAPs
Total transmitted length (bytes)
400
350
300
250
200
150
100
50
0
127 B
32
64
128
256
CoAP Block size (bytes)
43

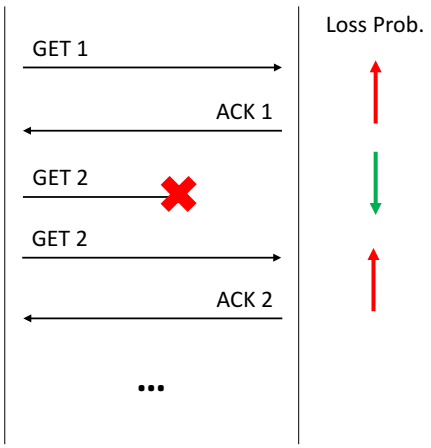

6lo+CoAP
IPv4+CoAP
6lo+CoAPs
IPv4+CoAPs
Overhead (%)
250
200
150
100
50
0
32
64
128
256
CoAP Block size (bytes)
44

Bitter-sweet Fragmentation

- Lower overhead (asymptotically)
  - ≈13 bytes per fragment vs. 28 bytes per packet
- Application-layer loss
  - If one fragment is lost, all others are dropped
  - Wasted bandwidth
- Reassembly complexity
  - Out-of-order fragments
  - Reassembly timer

45

Lost Packet (no fragmentation)

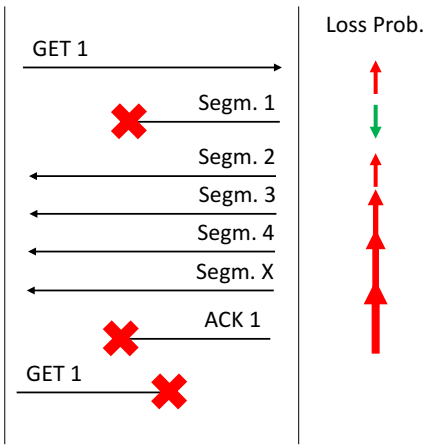


46

Lost Packet (no fragmentation)

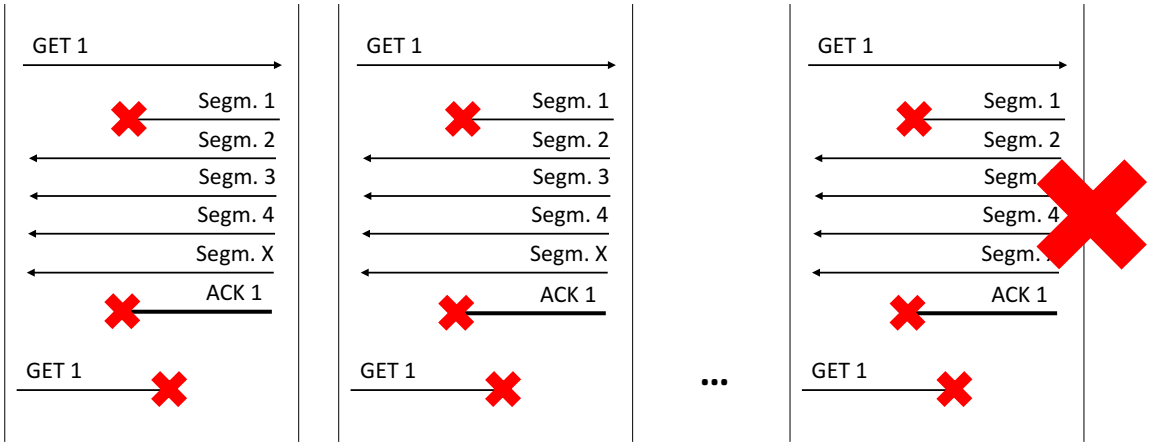
47

Lost Packet (with fragmentation)



48

Lost Packet (with fragmentation)



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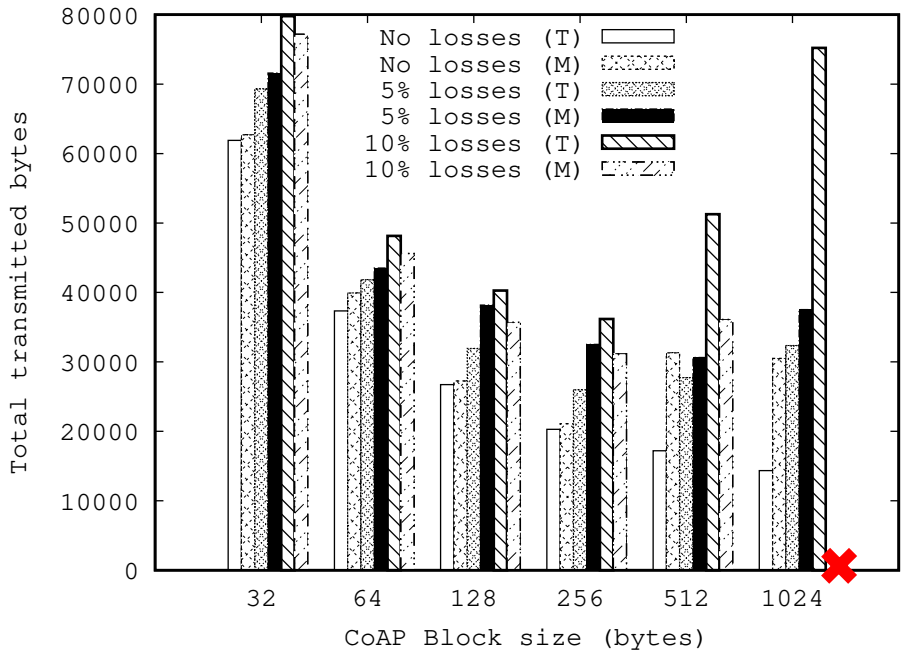

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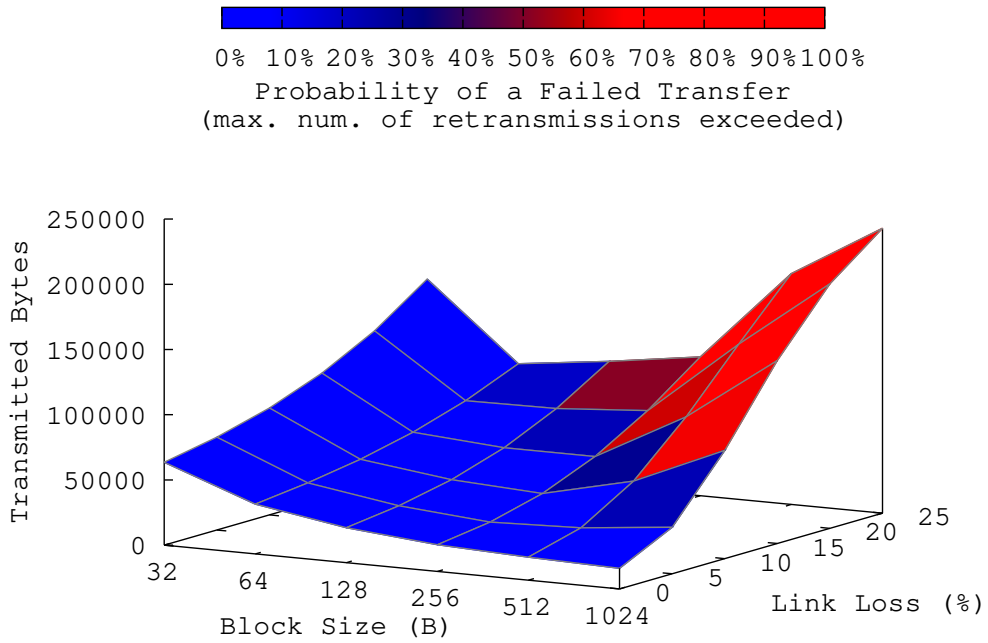
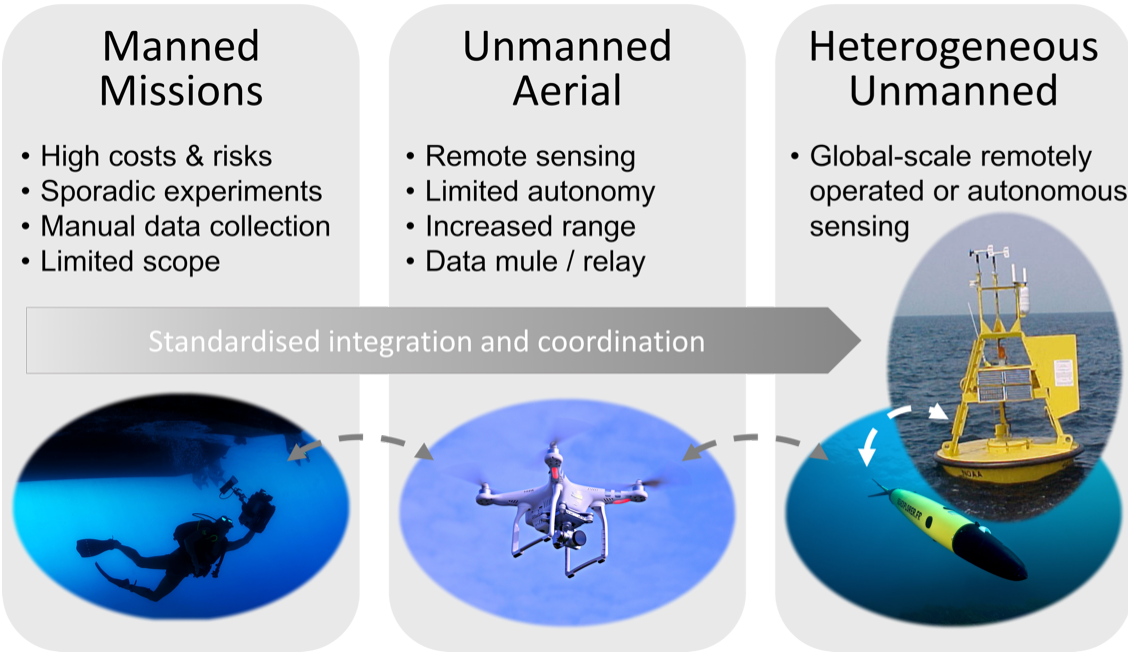

0% 10% 20% 30% 40% 50% 60% 70% 80% 90%100%
Probability of a Failed Transfer
(max. num. of retransmissions exceeded)
Transmitted Bytes
250000
200000
150000
100000
50000
0
32
64
128
256
512
1024
Block Size (B)
0
5
10
15
20
25
Link Loss (%)


Manned Missions
• High costs & risks
• Sporadic experiments
• Manual data collection
• Limited scope
Unmanned Aerial
• Remote sensing
• Limited autonomy
• Increased range
• Data mule / relay
Heterogeneous Unmanned
• Global-scale remotely operated or autonomous sensing
Standardised integration and coordination
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Heterogeneous networking in challenging environments

Limited power and lossy networks
Software-defined and disruption-tolerant networking
Robust, hybrid and flexible networks

NTNU – Trondheim
Norwegian University of
Science and Technology

Thank you!

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