Ghost Peak:

Practical Distance Reduction Attacks Against HRP UWB Ranging

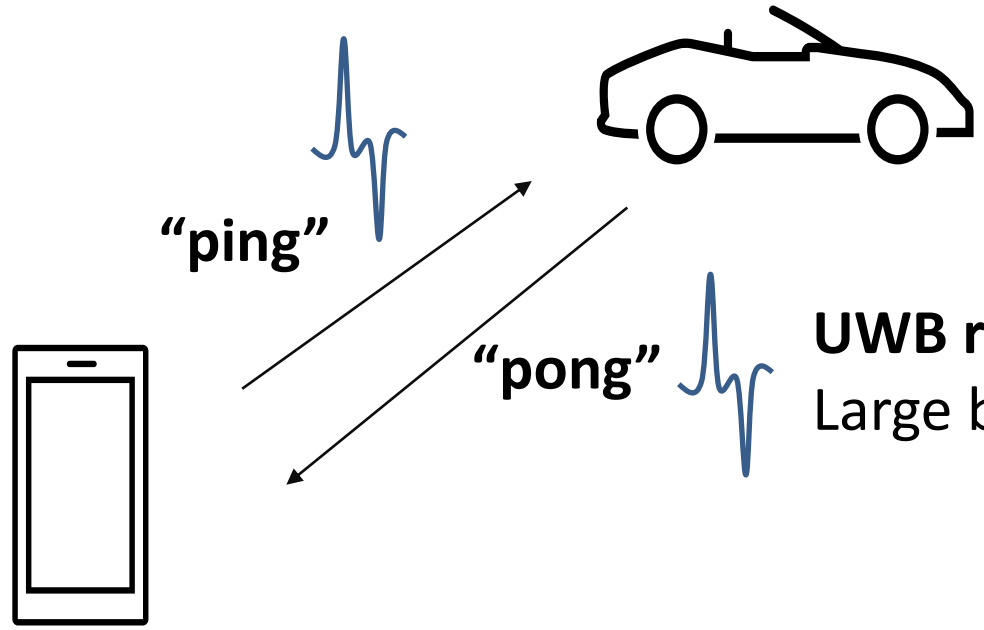
P. Leu[1*], G. Camurati[1*], A. Heinrich[2], M. Roeschlin[1], C. Anliker[1],
M. Hollick[2], S. Capkun[1], J. Classen[2]

[1] ETH zürich [2] SEEMOO SECURE MOBILE NETWORKING TECHNISCHE UNIVERSITÄT DARMSTADT

[*]Equal contribution

https://securepositioning.com/ghost-peak/
https://github.com/seemoo-la/uwb-sniffer

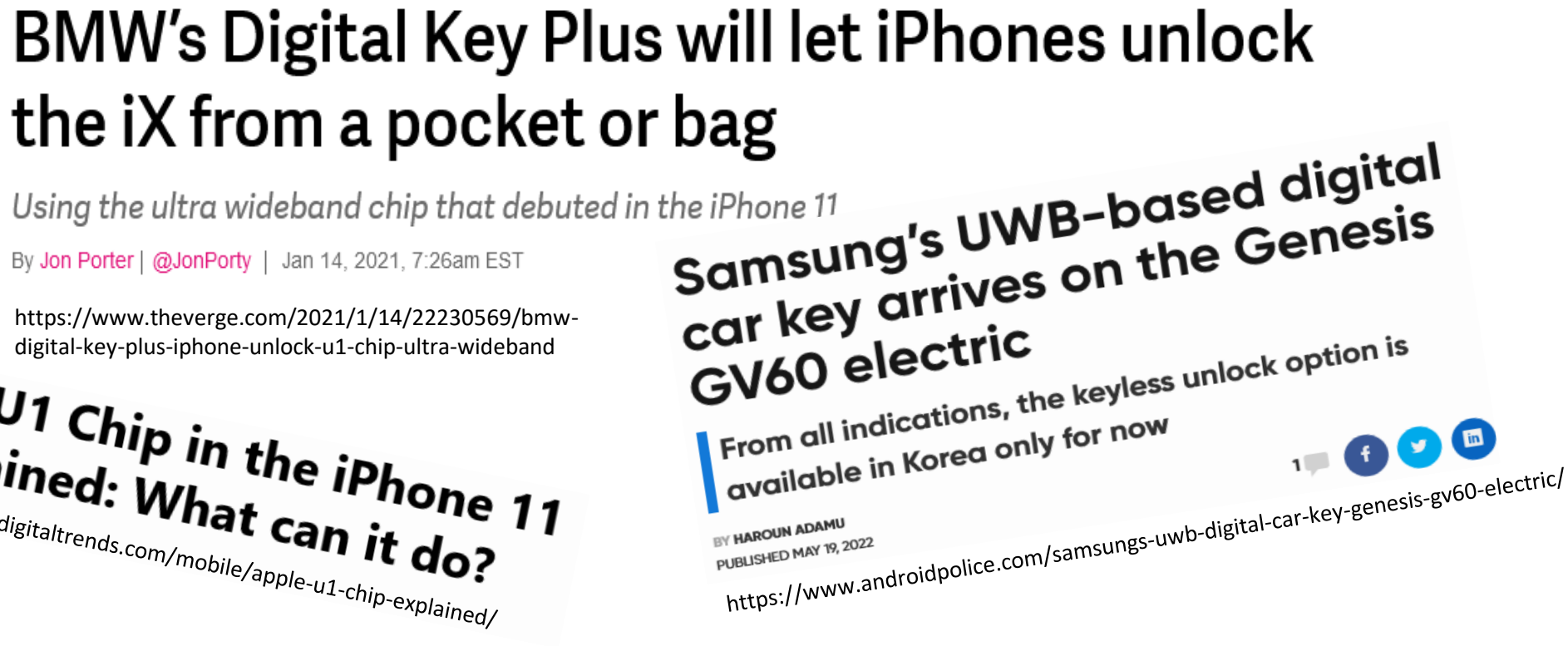
Background: Ultra Wide Band (UWB) ranging in a nutshell



UWB radio pulses
Large bandwidth => high time/distance accuracy

Distance = time-of-flight x speed-of-light

IEEE802.15z High-Repetition Pulse (HRP) UWB is now in your phone, watch, car…



BMW's Digital Key Plus will let iPhones unlock the iX from a pocket or bag

Using the ultra wideband chip that debuted in the iPhone 11

By Jon Porter | @JonPorty | Jan 14, 2021, 7:26am EST

https://www.theverge.com/2021/1/14/22230569/bmw-digital-key-plus-iphone-unlock-u1-chip-ultra-wideband

The U1 Chip in the iPhone 11 explained: What can it do?

https://www.digitaltrends.com/mobile/apple-u1-chip-explained/

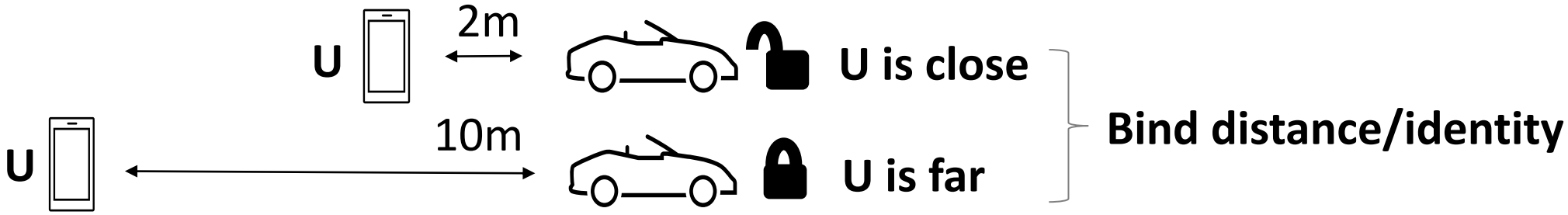
Samsung's UWB-based digital car key arrives on the Genesis GV60 electric

From all indications, the keyless unlock option is available in Korea only for now

BY HAROUN ADAMU
PUBLISHED MAY 19, 2022

https://www.androidpolice.com/samsungs-uwb-digital-car-key-genesis-gv60-electric/

Motivation: ideal secure ranging and previous solutions



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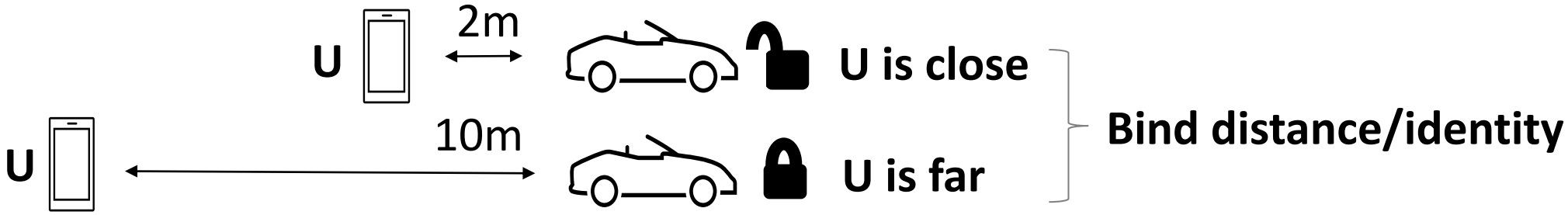

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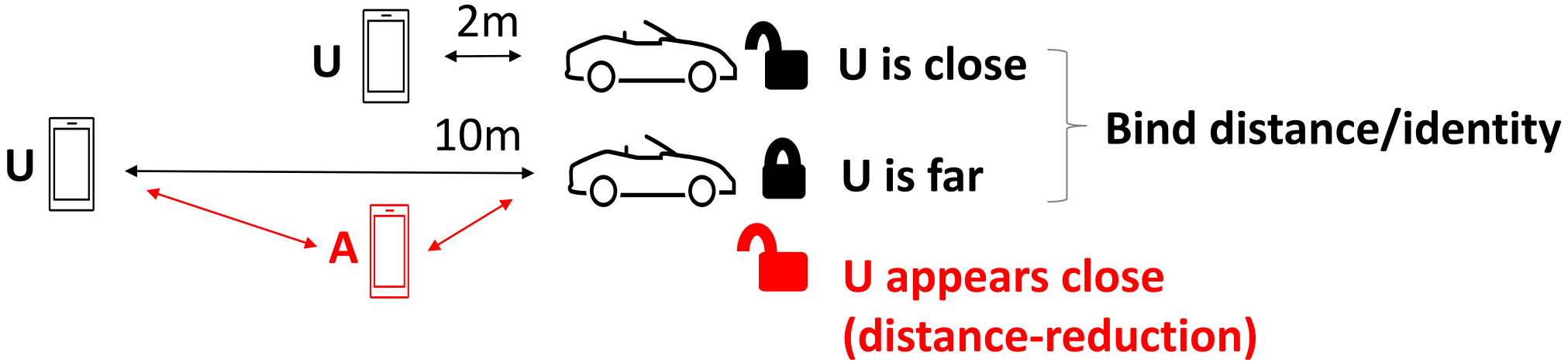

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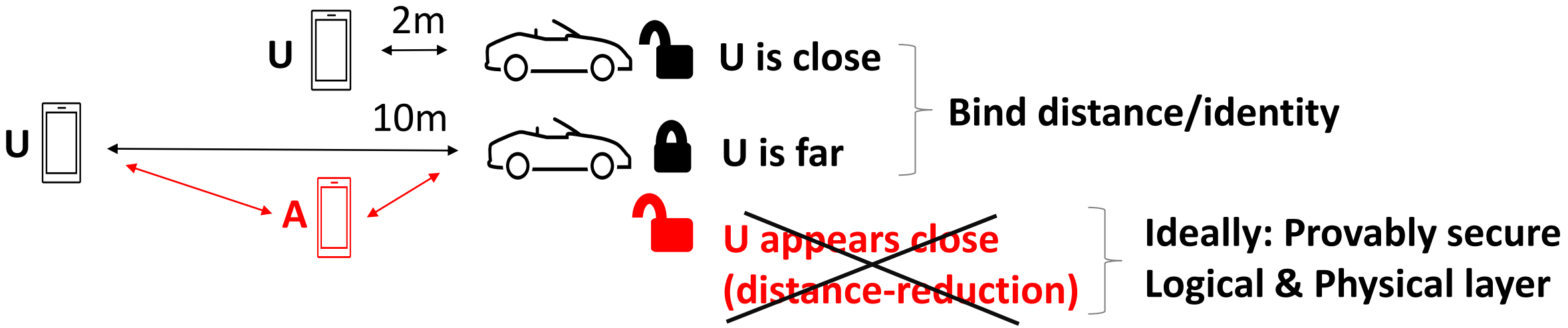

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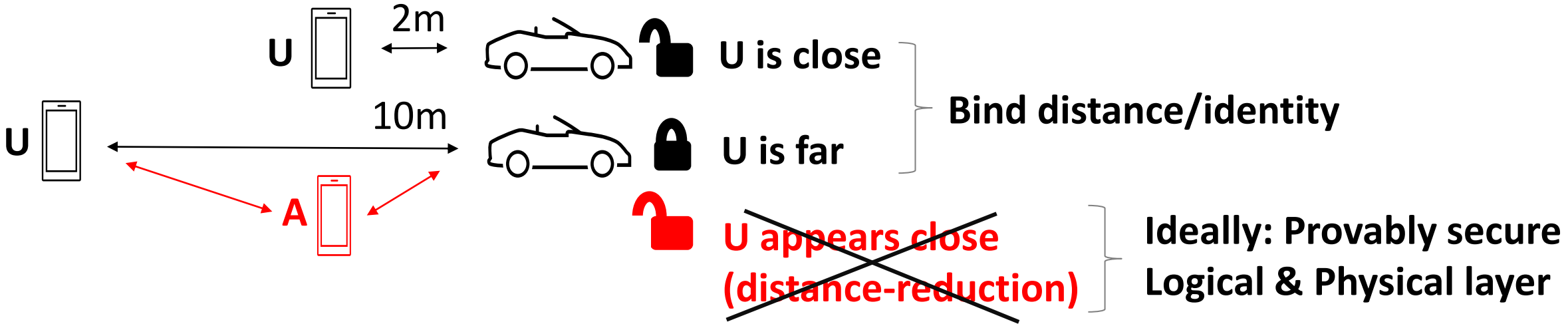

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Insecure solutions: e.g., signal strength (RSSI)

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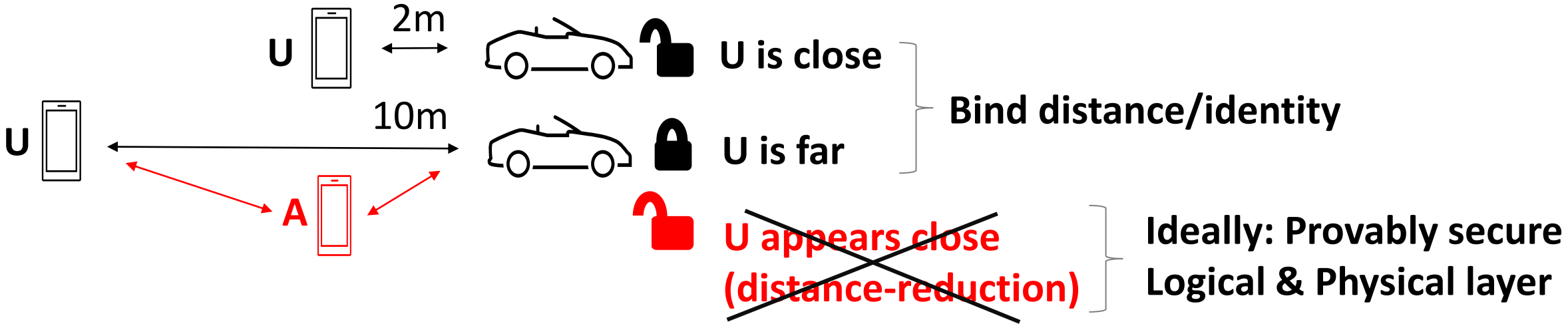

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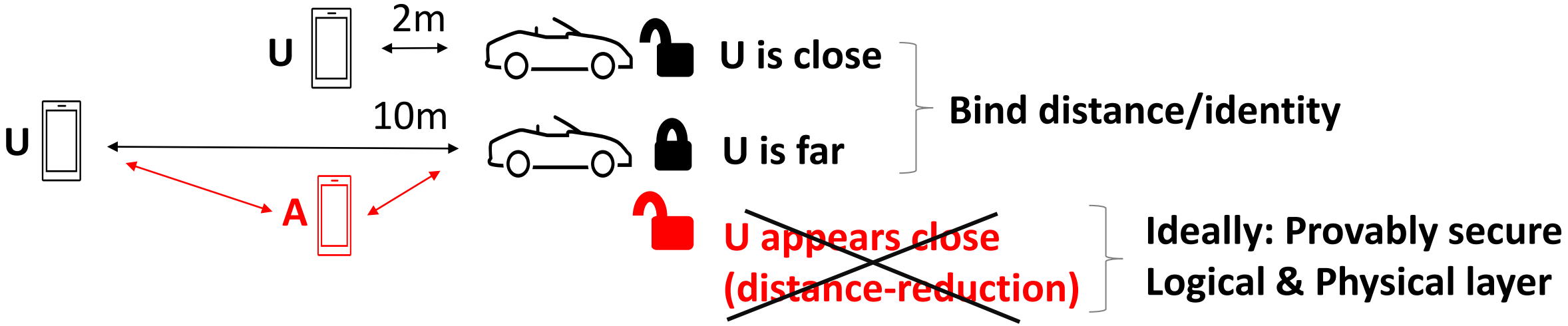

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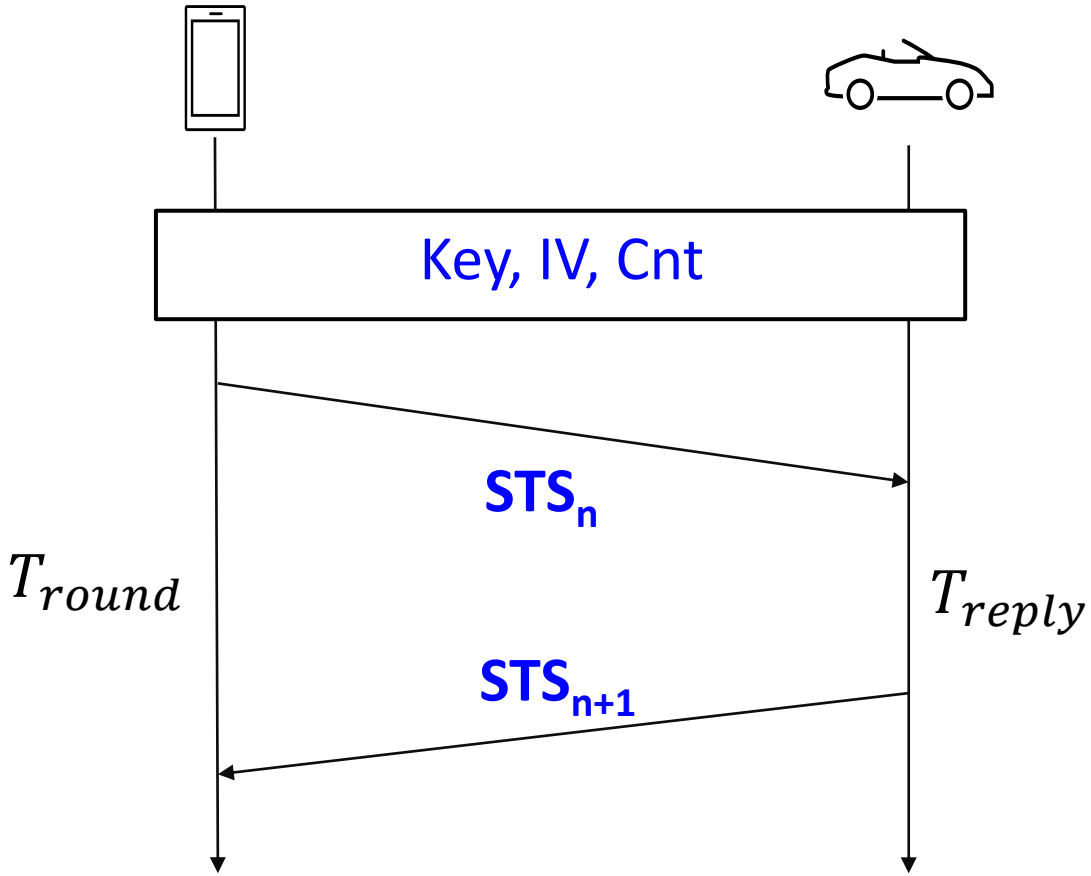
What about HRP UWB? Is it secure?

Background: IEEE802.15z HRP UWB logical layer (simplified)



$$d = c\,(T_{round} - T_{reply})/2$$

STS = Scrambed Time Sequence

- E.g., 4096 pulses
- Cryptographycally secure sequence
- AES in counter mode

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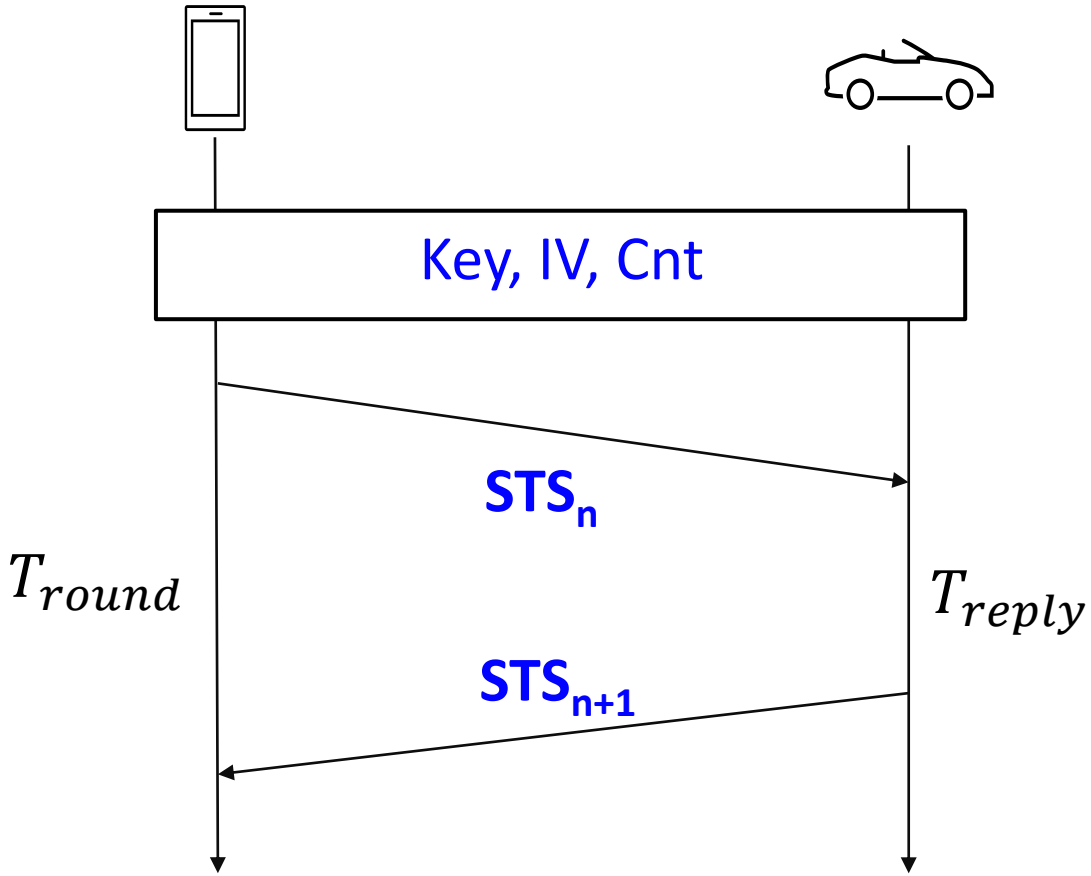

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Unpredictable
=> An attacker cannot anticipate transmission to shorten the distance

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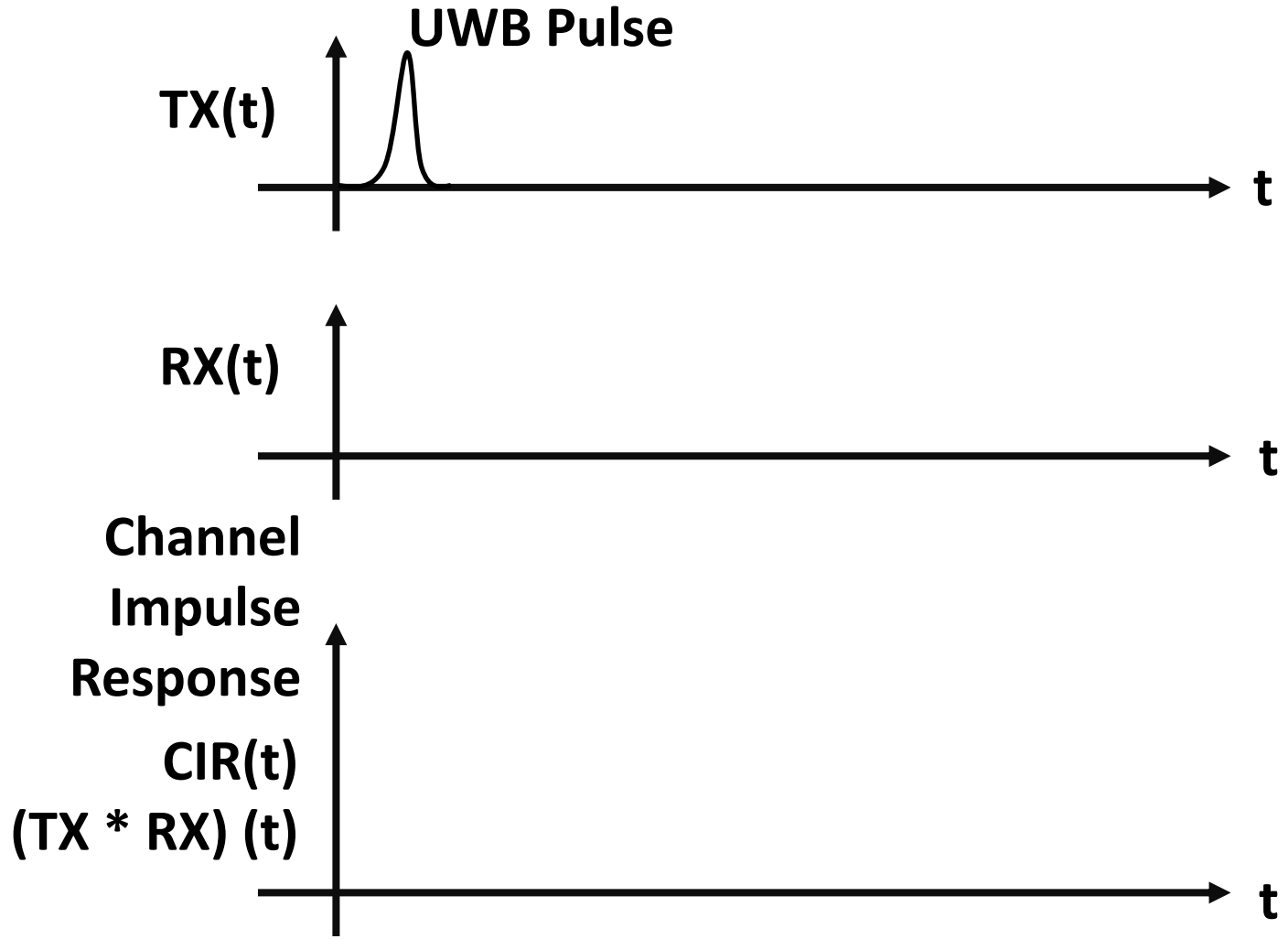

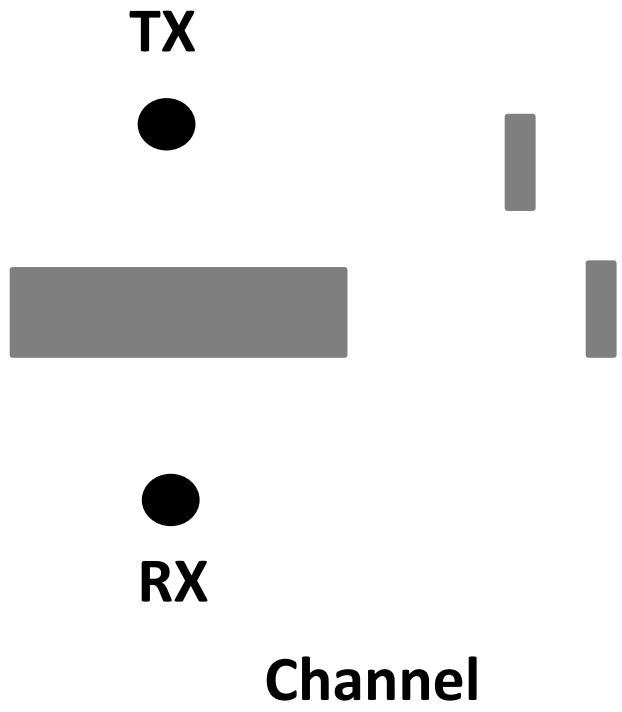

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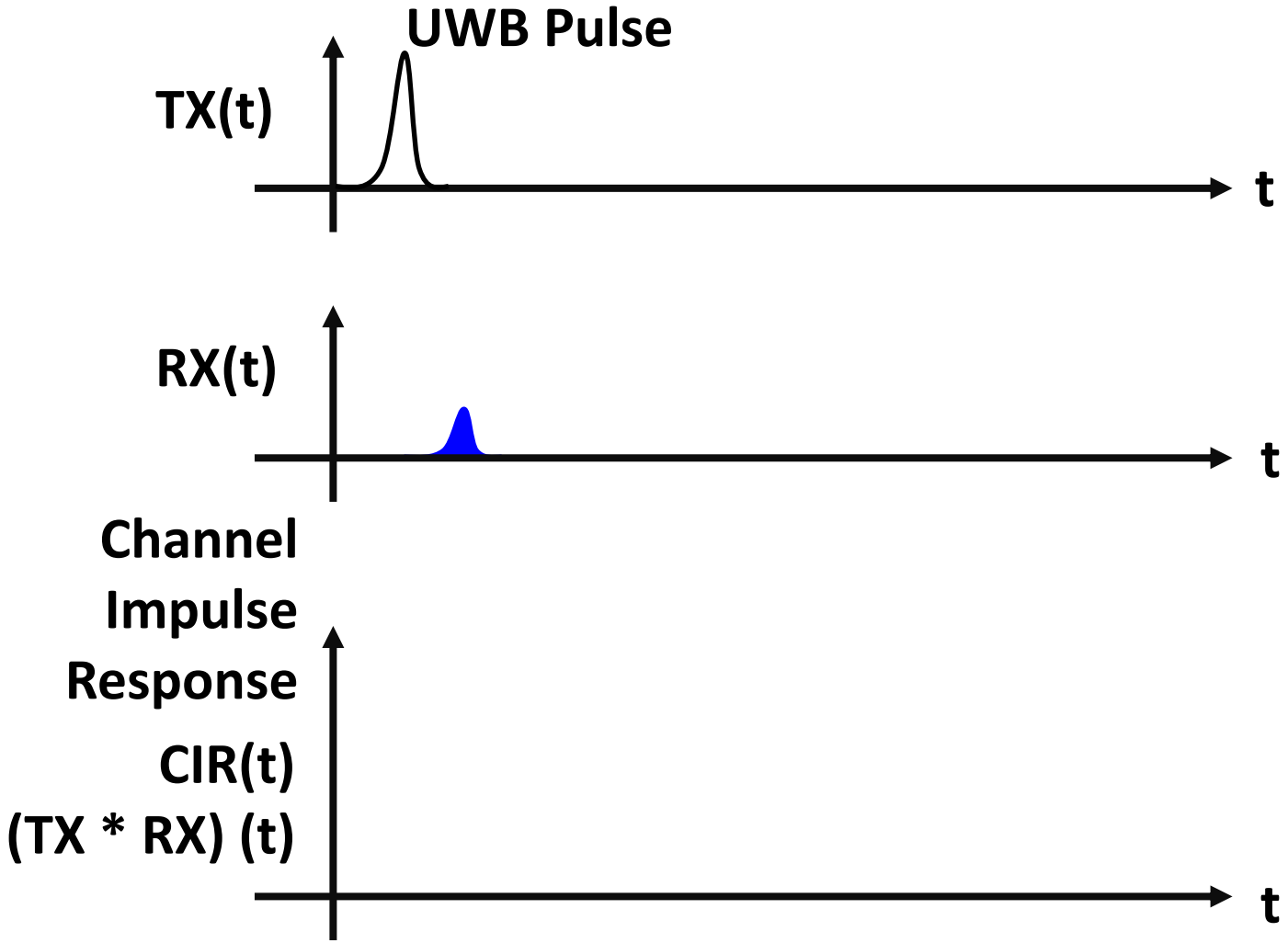

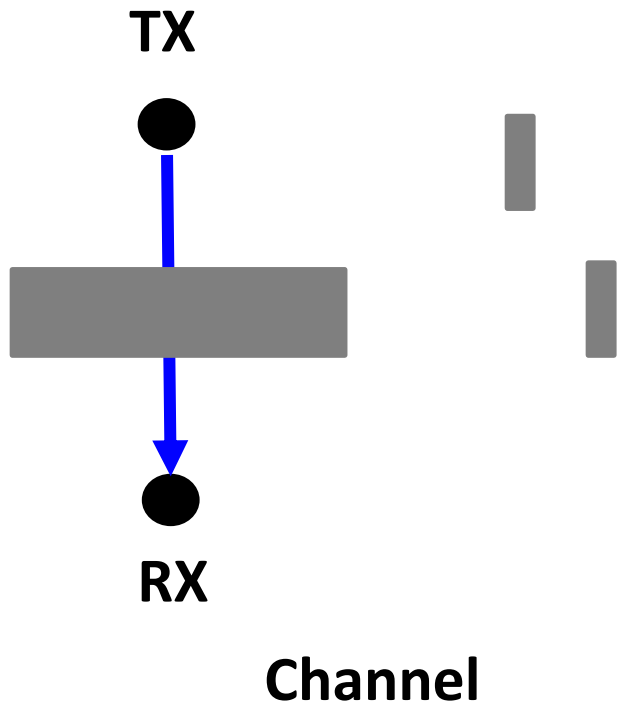

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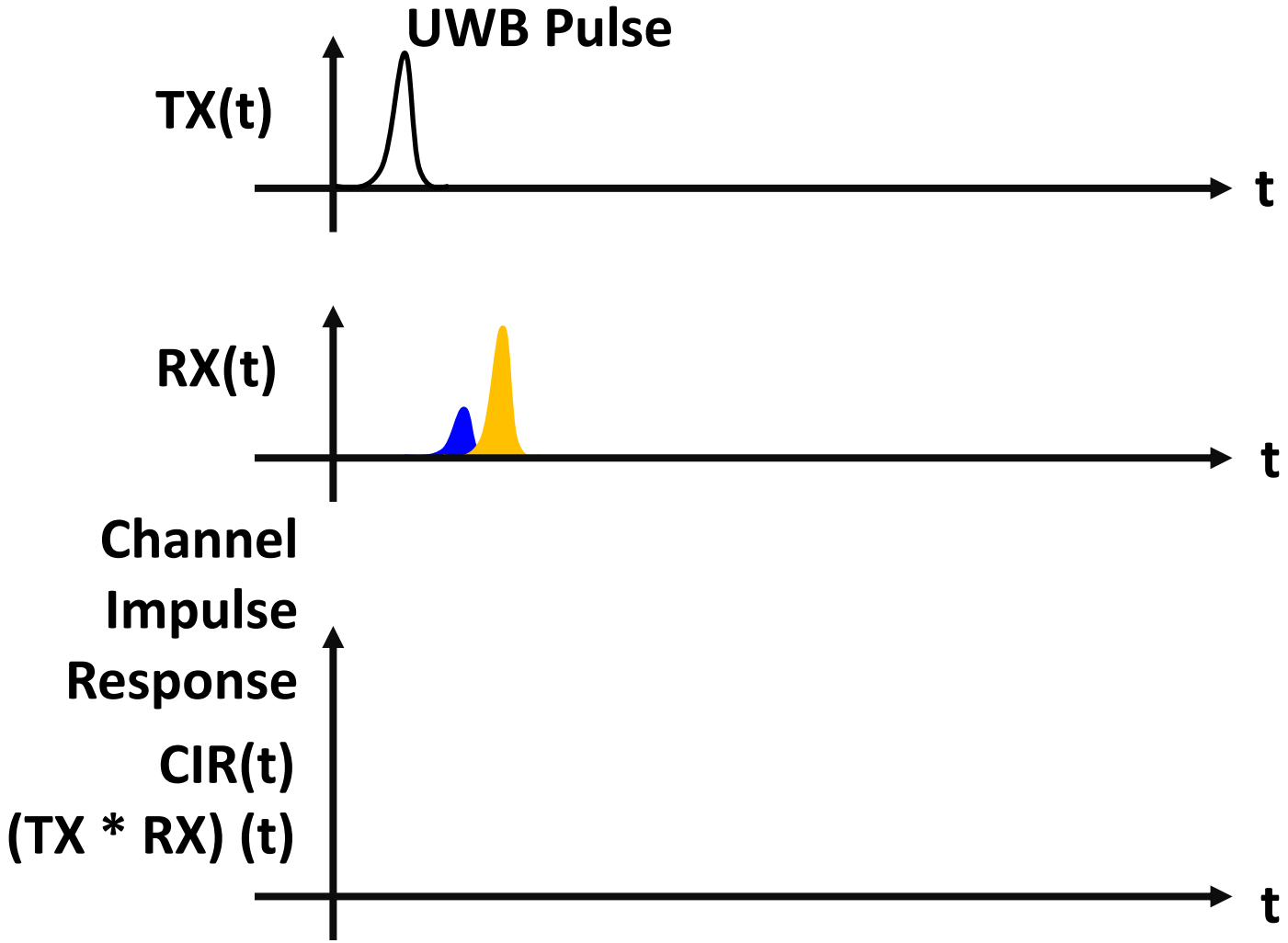

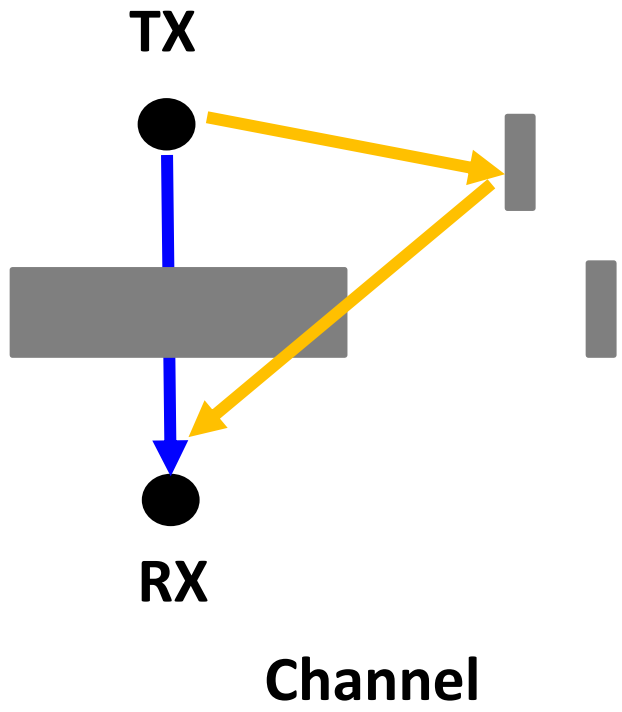

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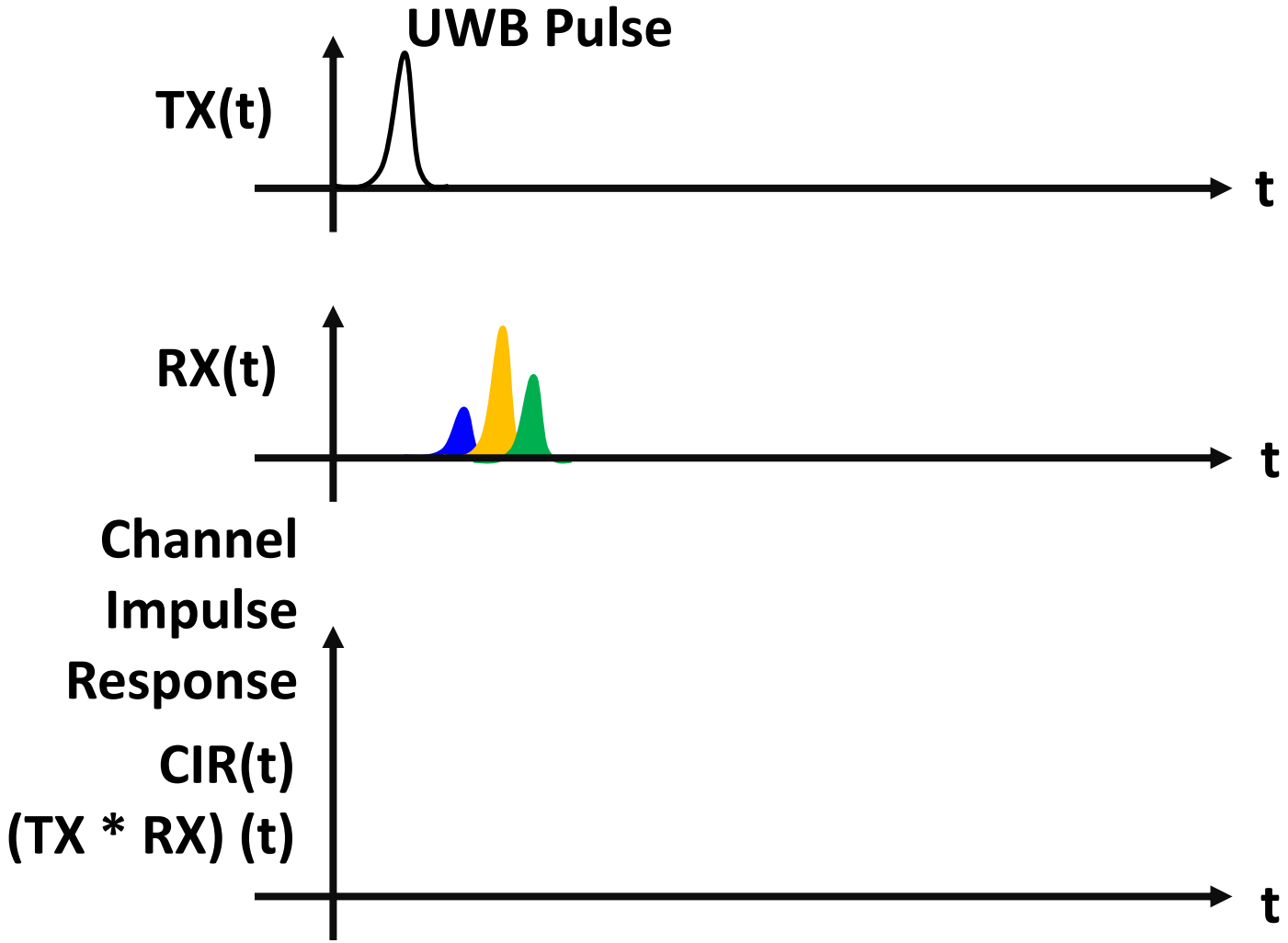

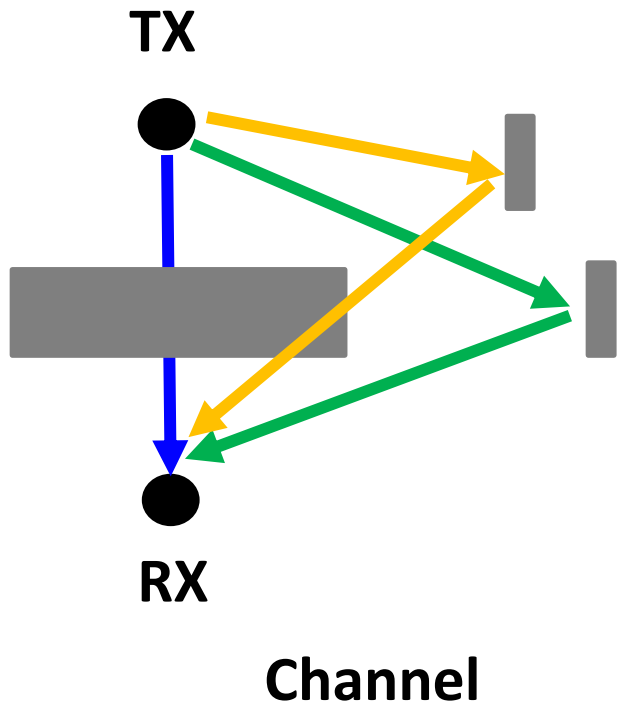

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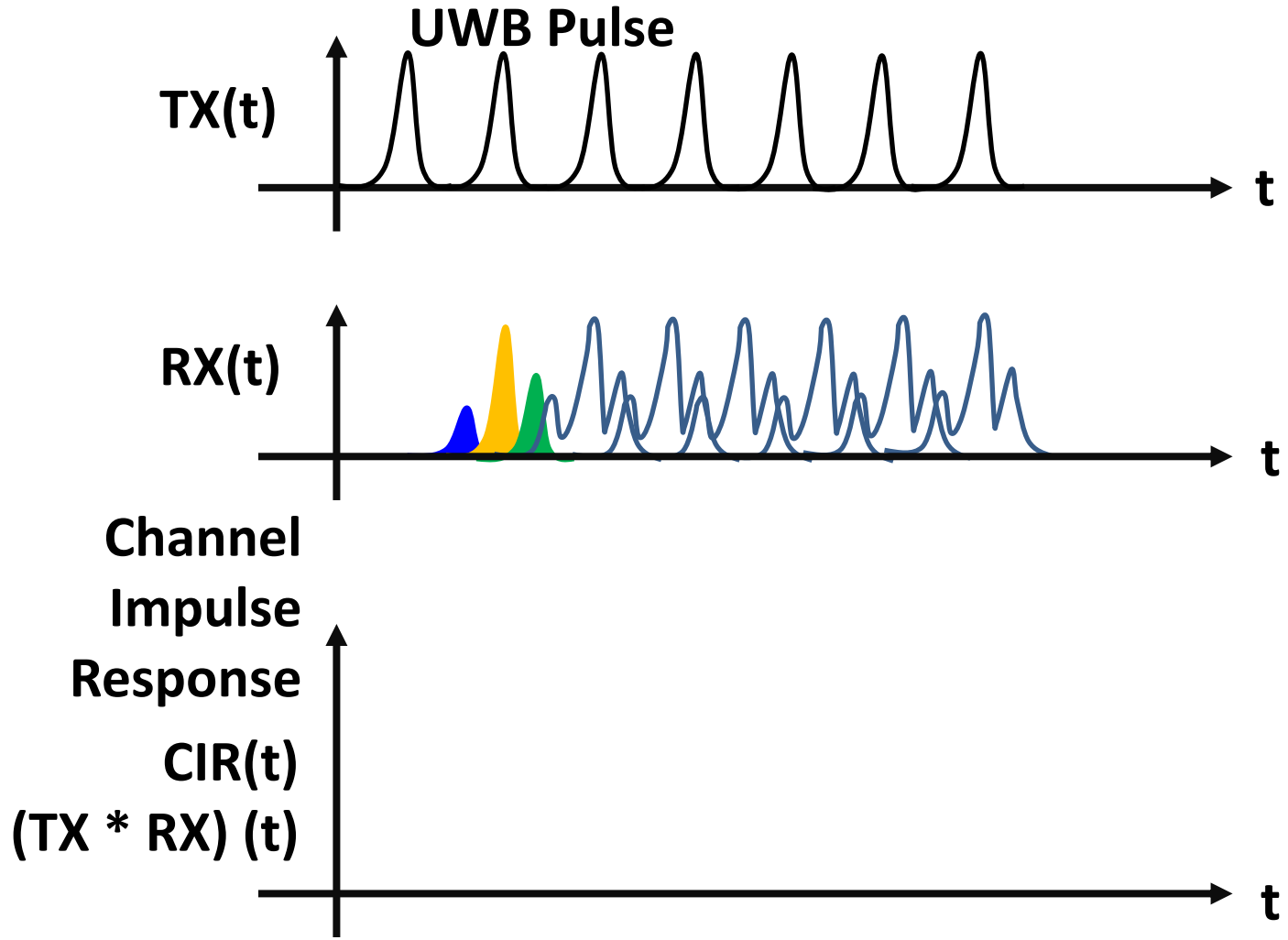

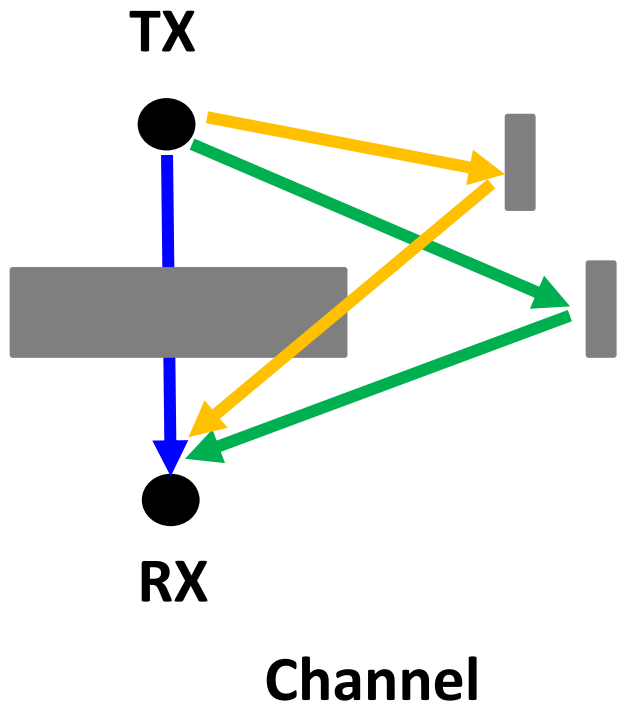

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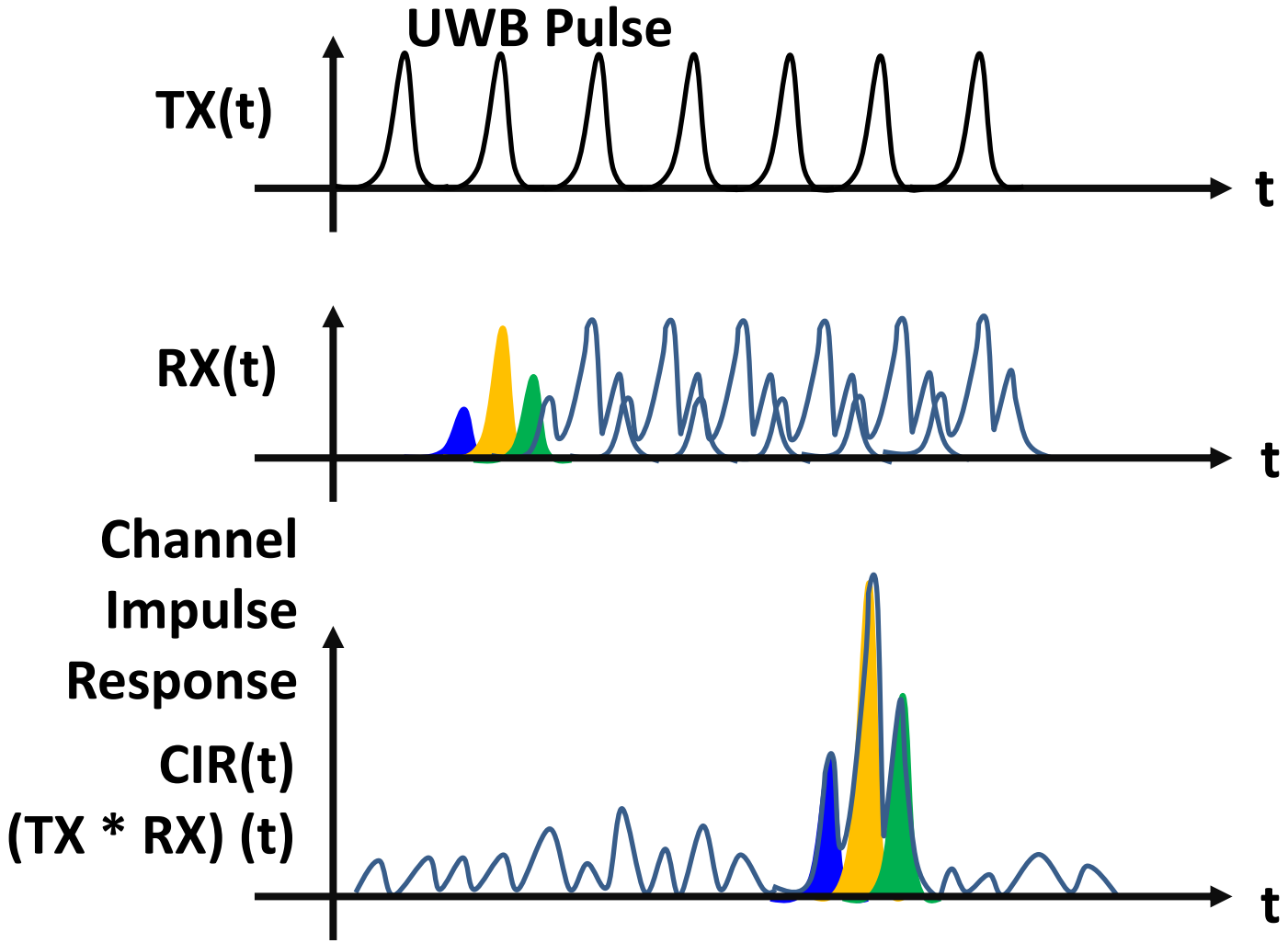

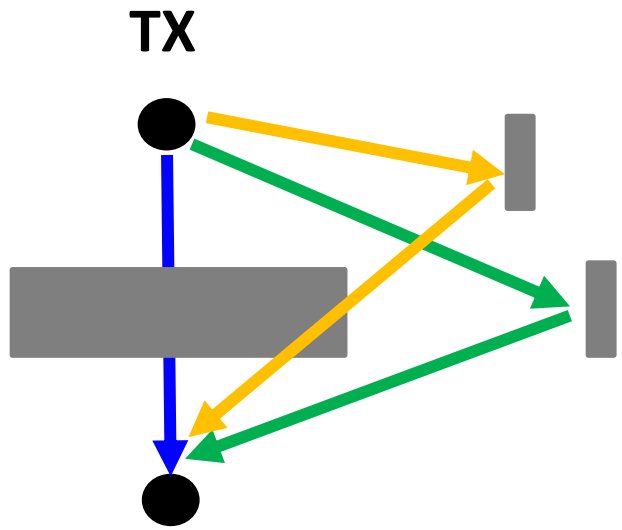

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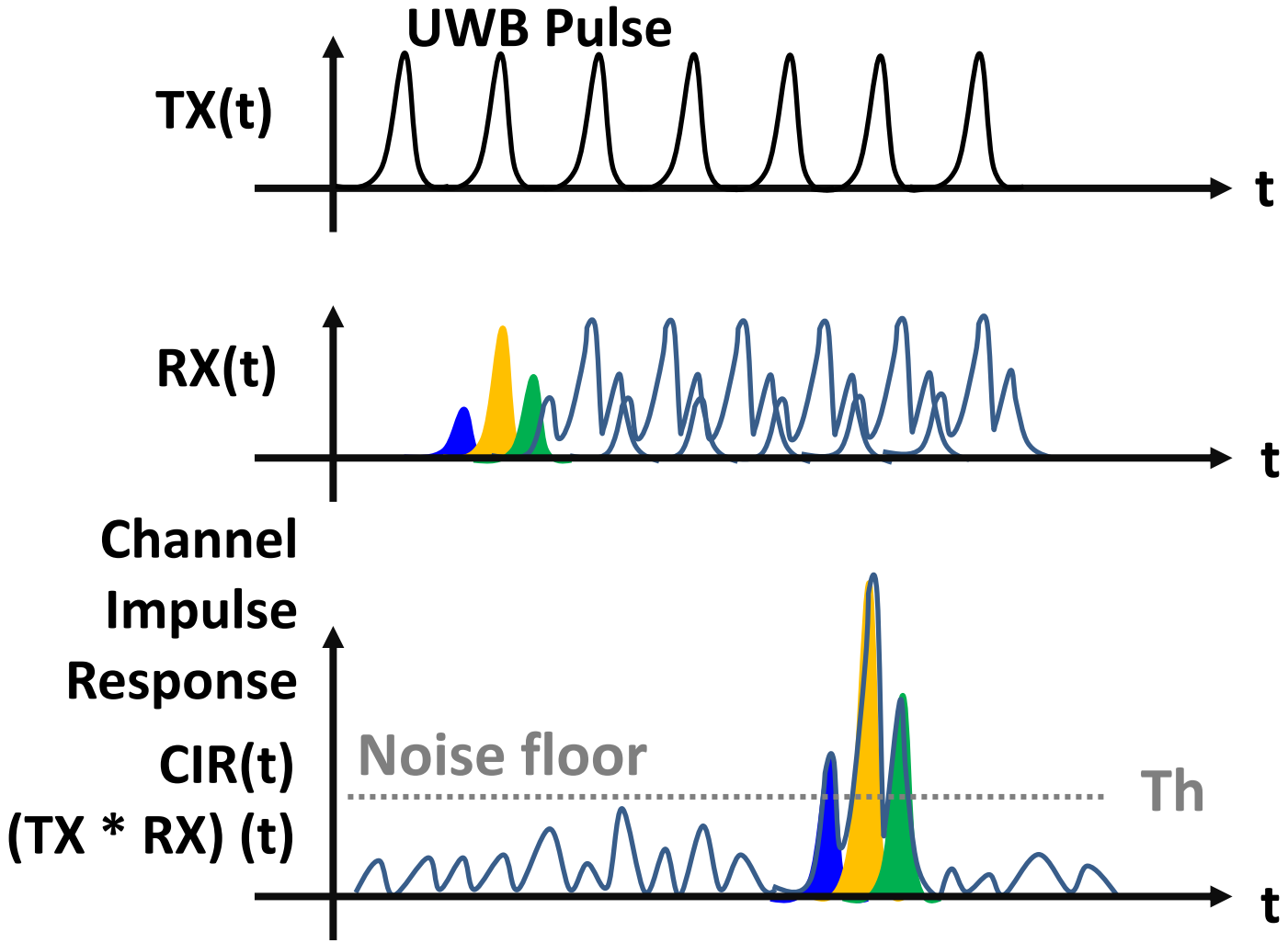

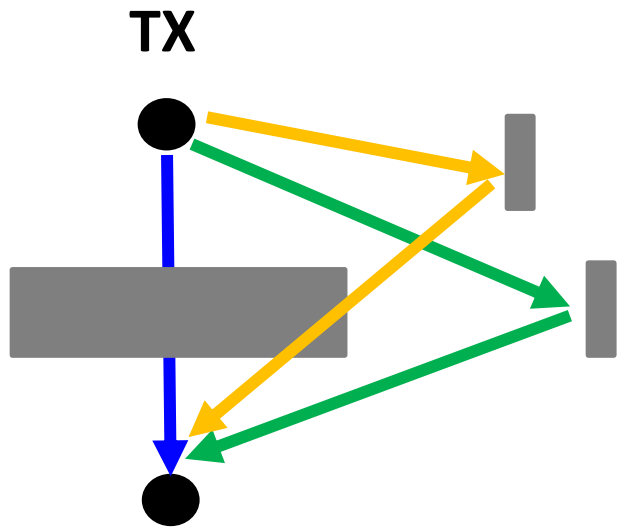

Channel

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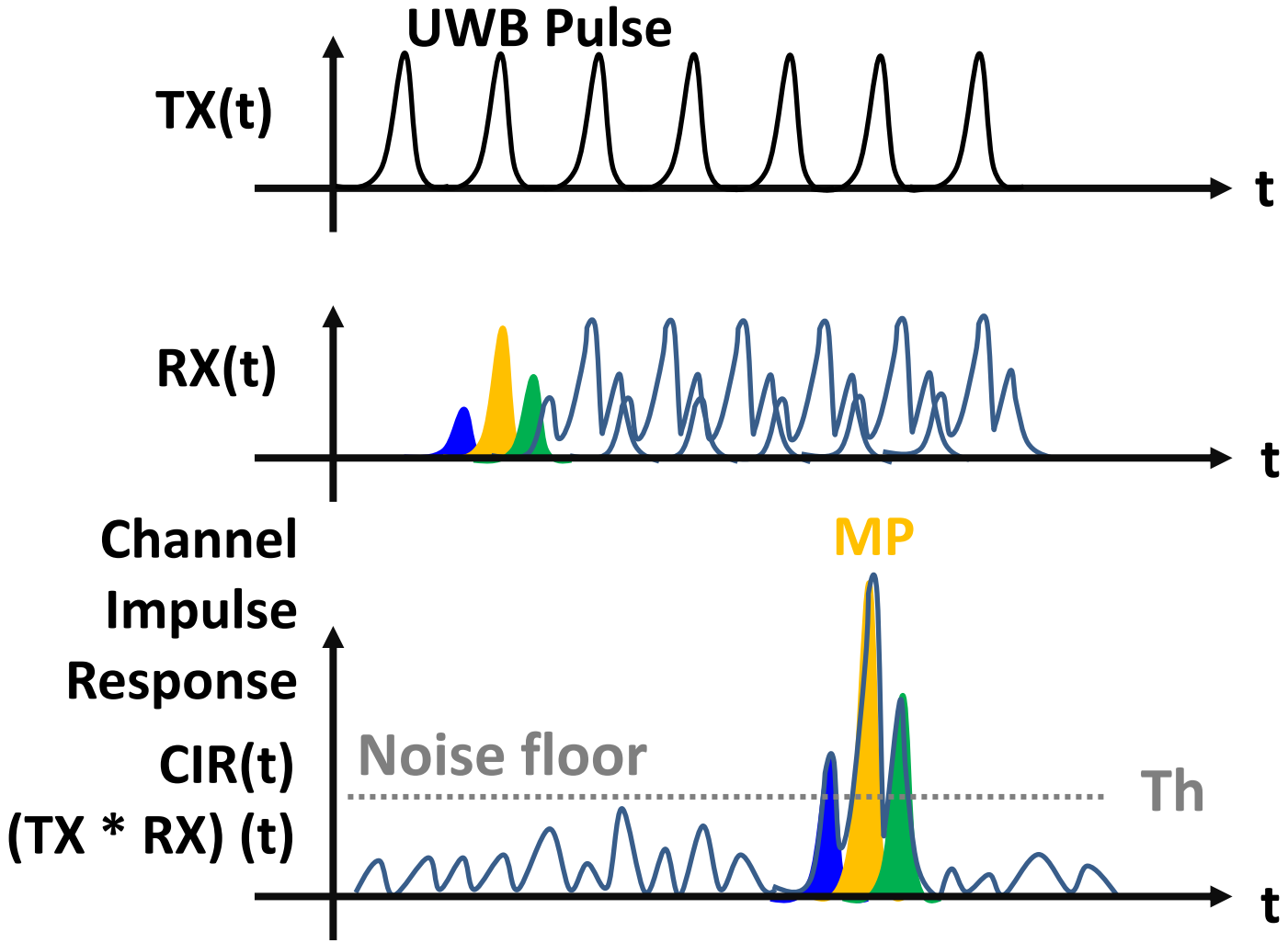

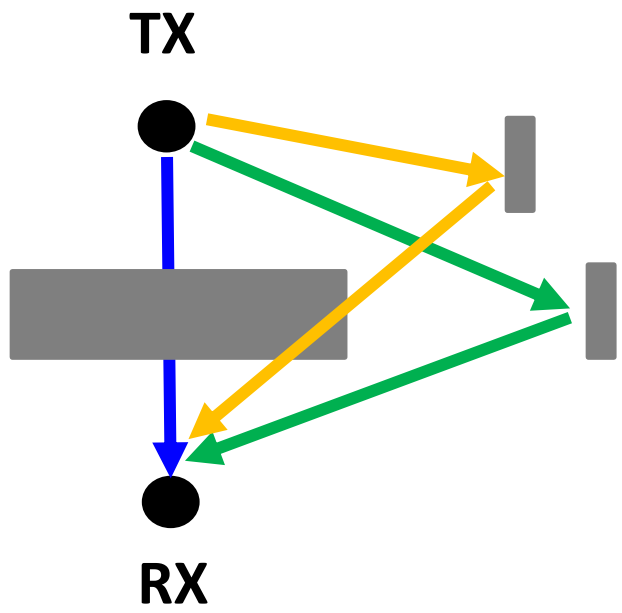

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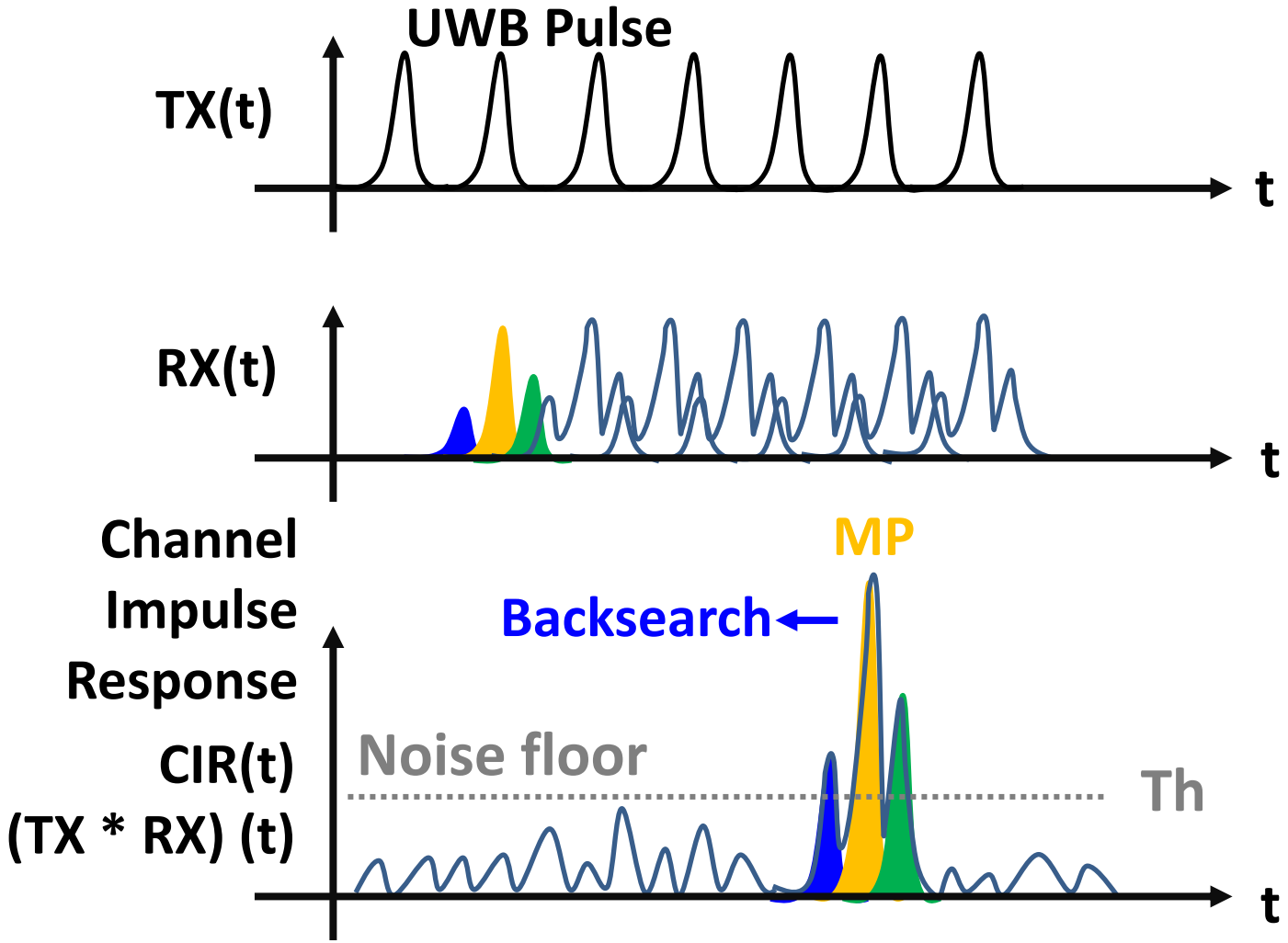

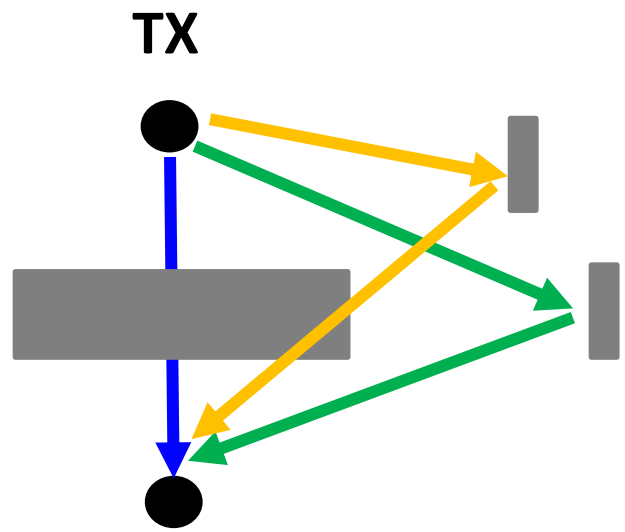

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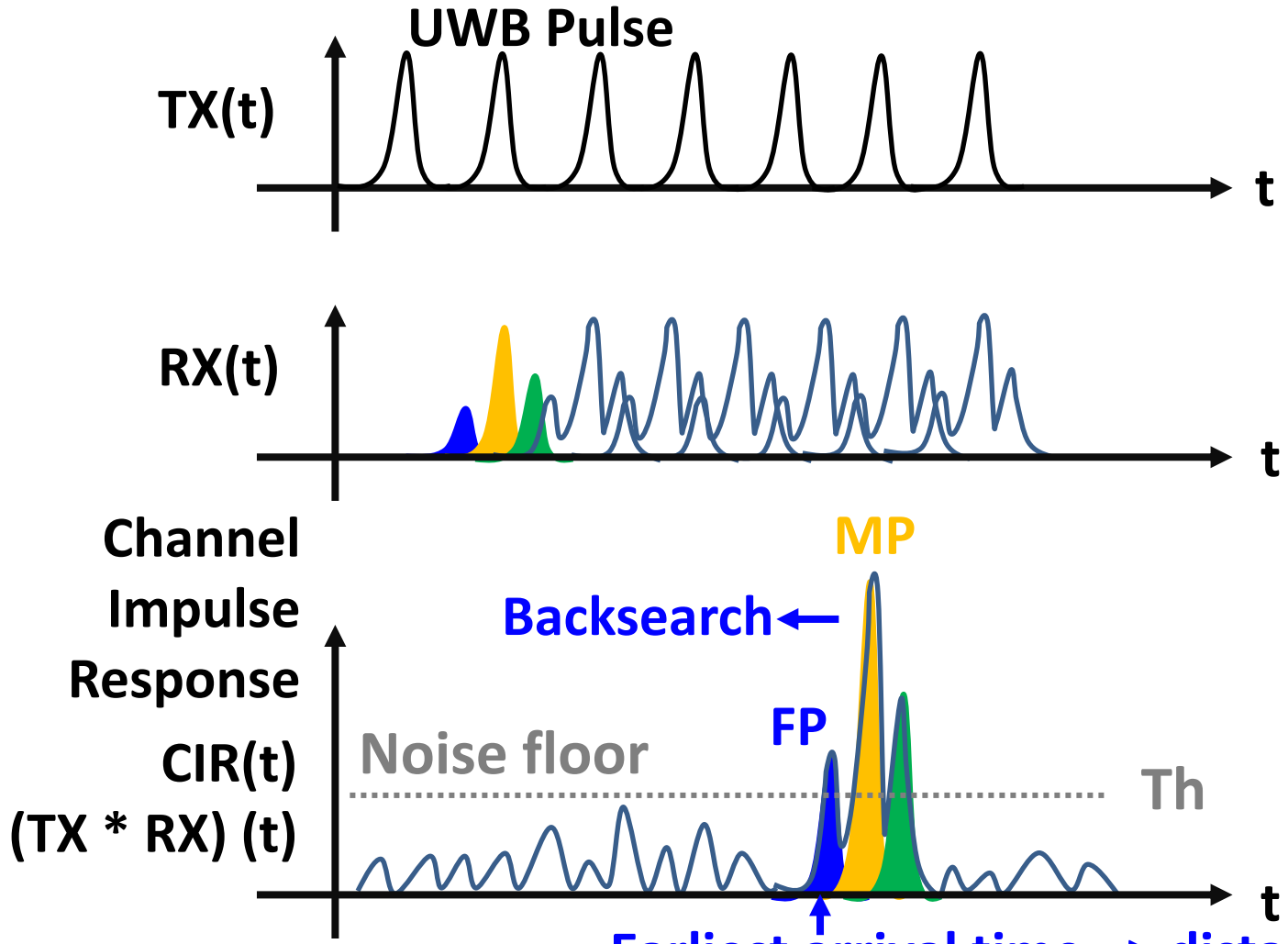
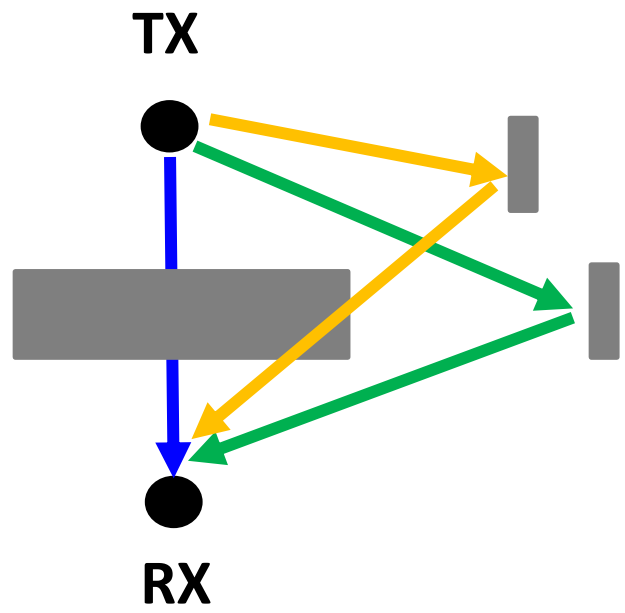
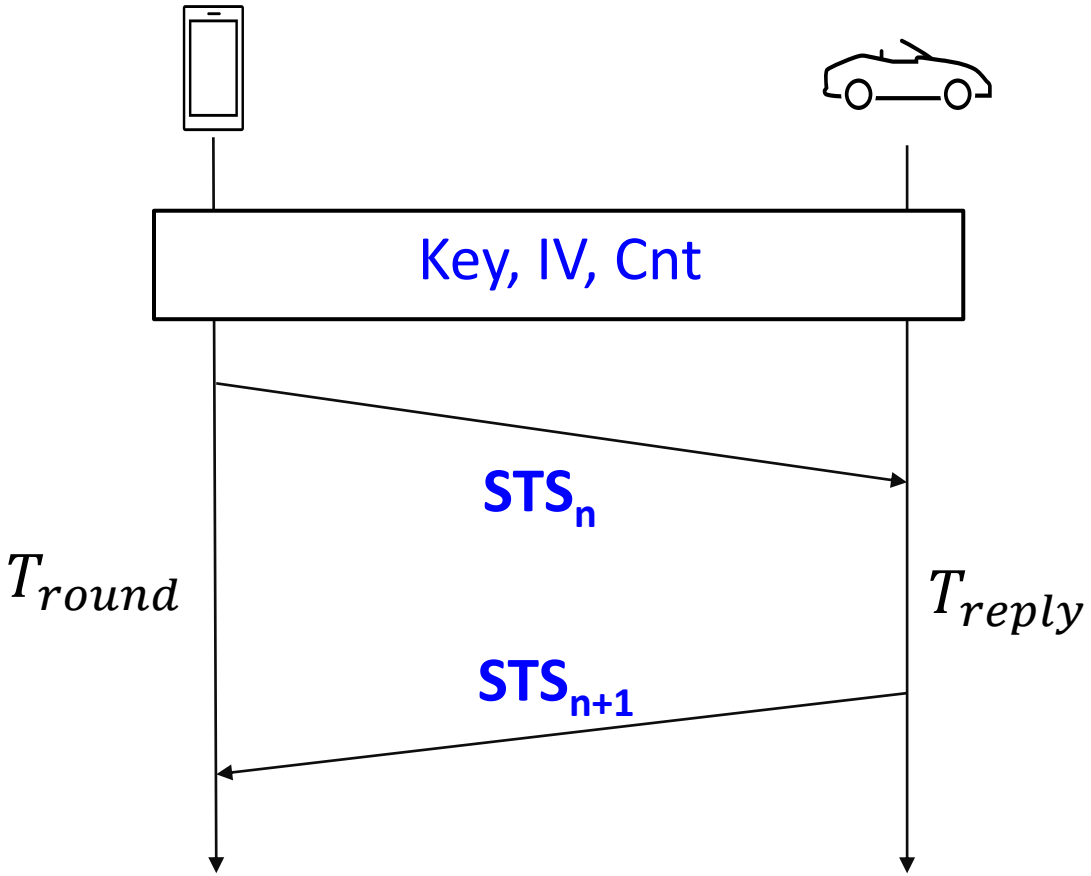




Ghost Peak: reactively inject a fake early path (simplified)



Threat model

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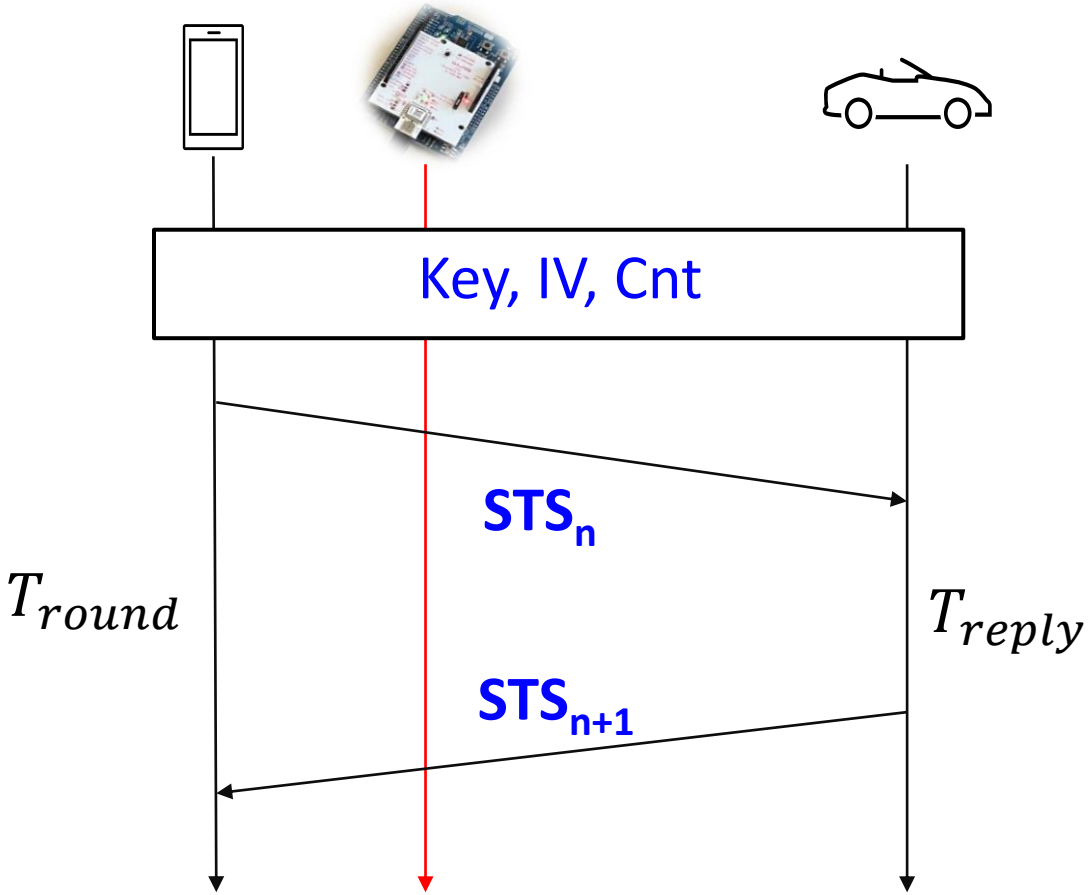

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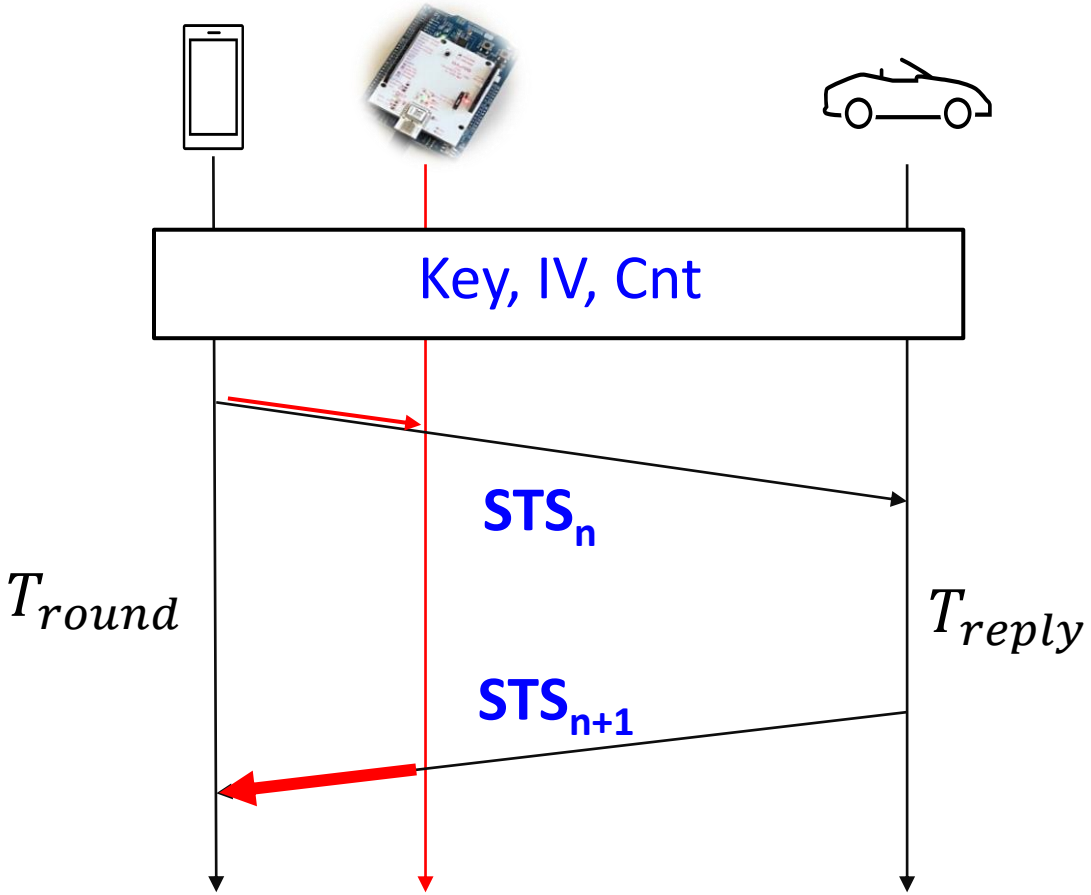

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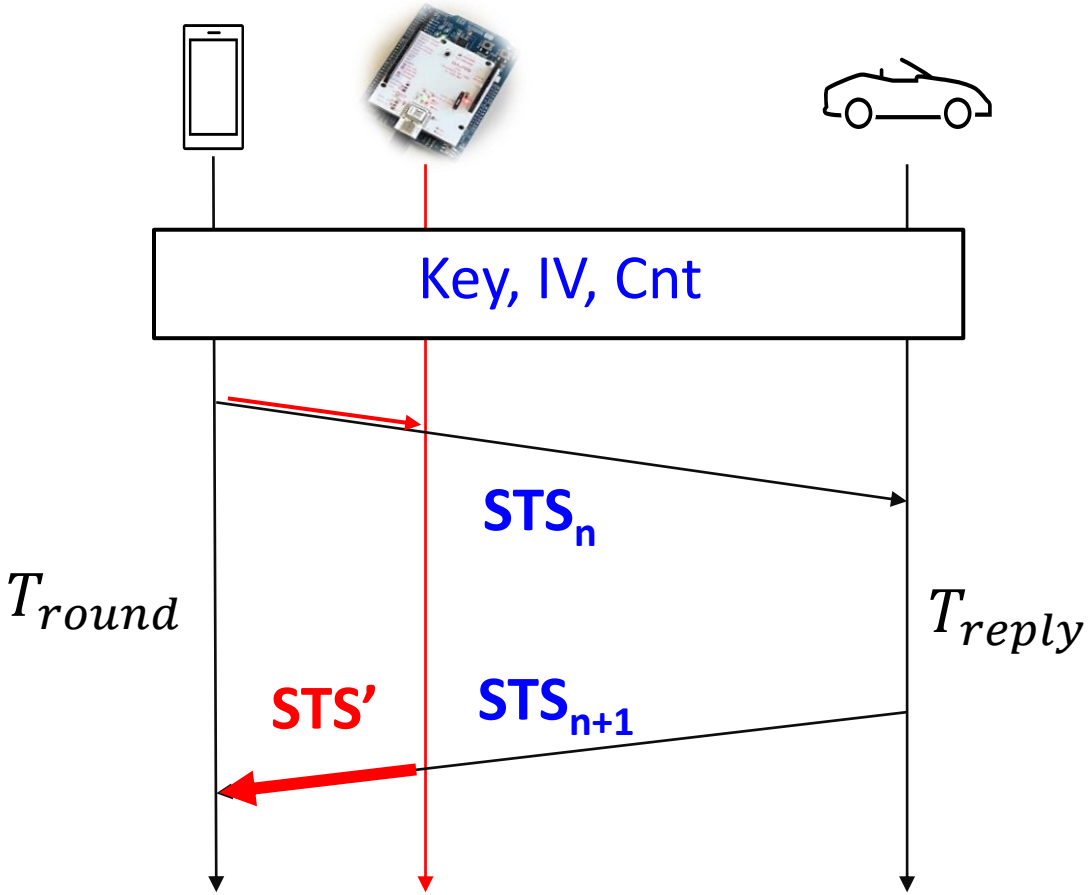

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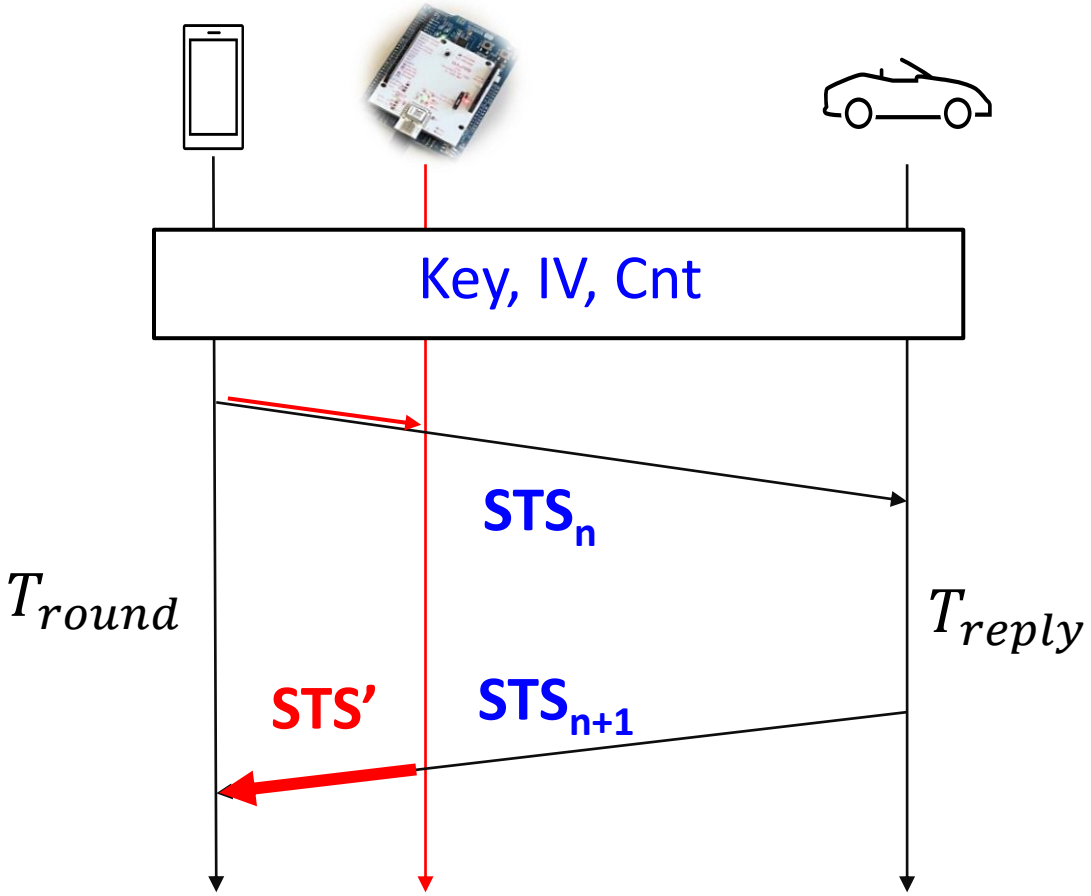

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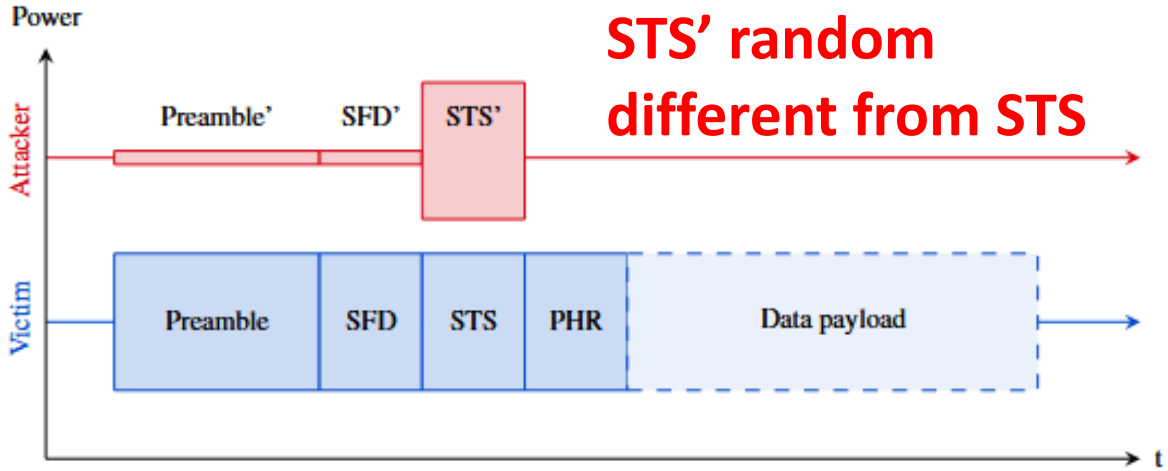

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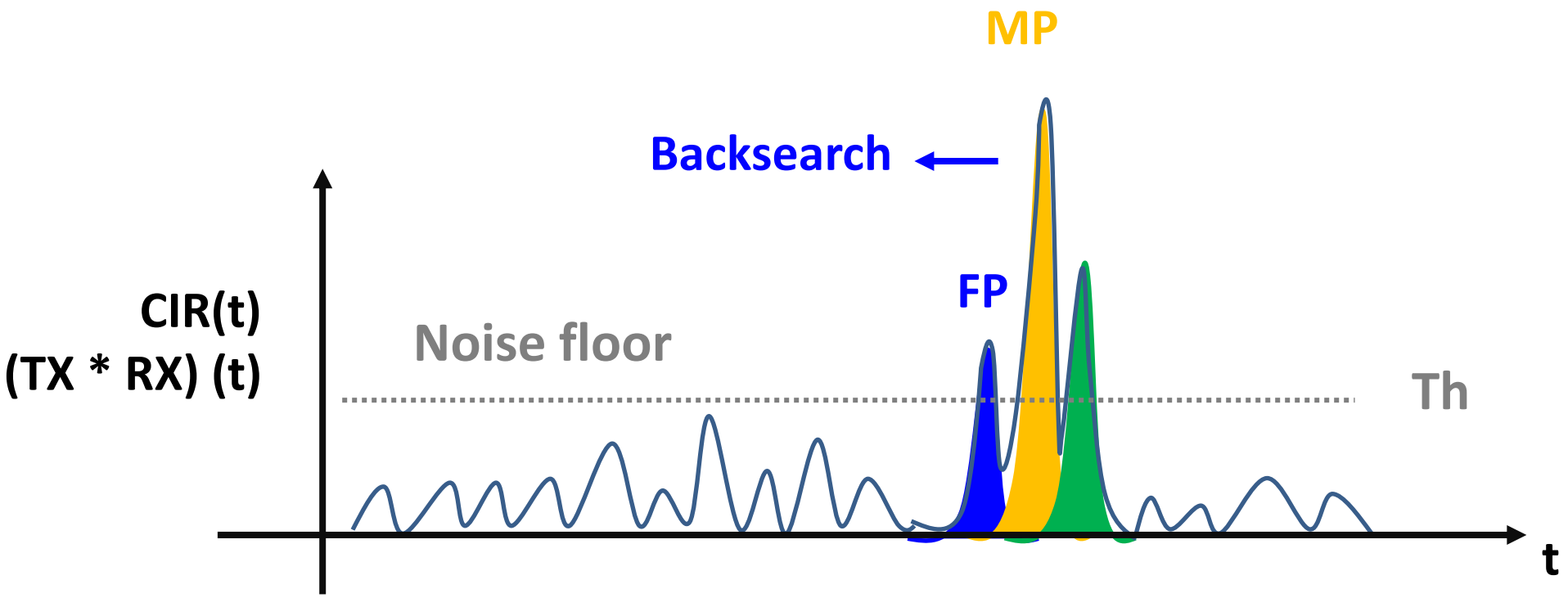

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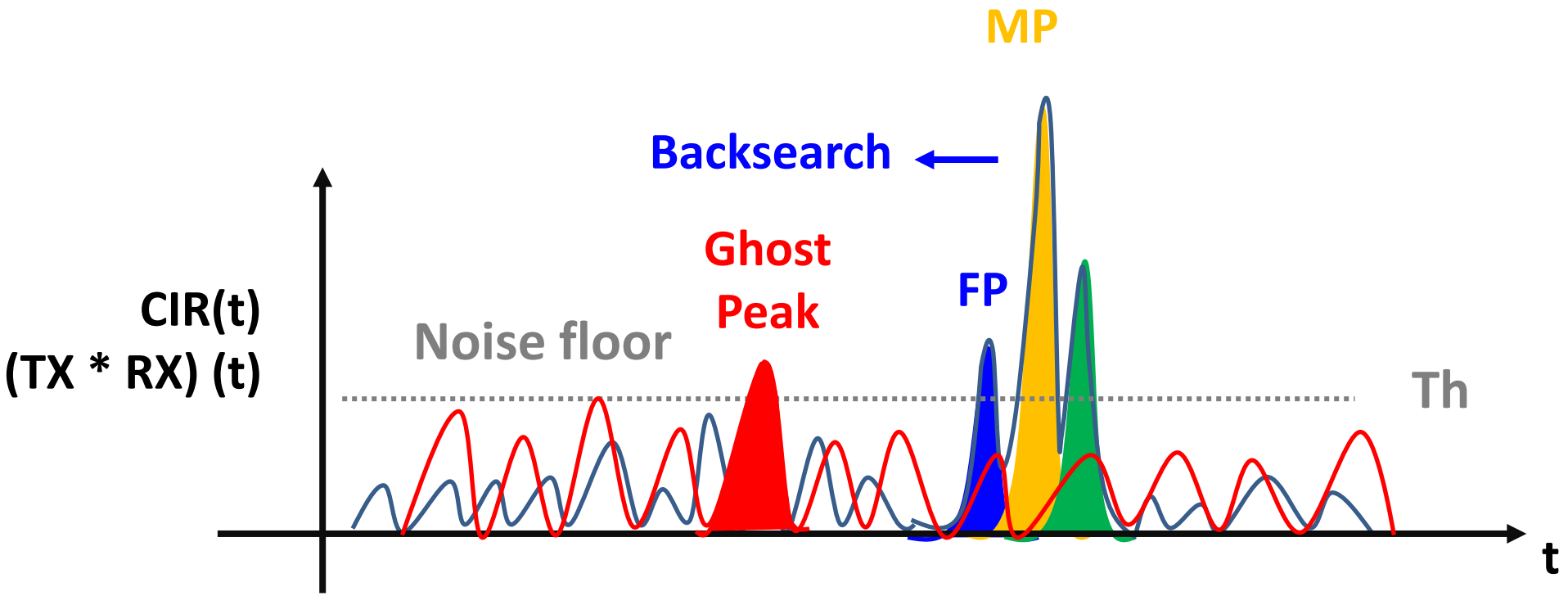

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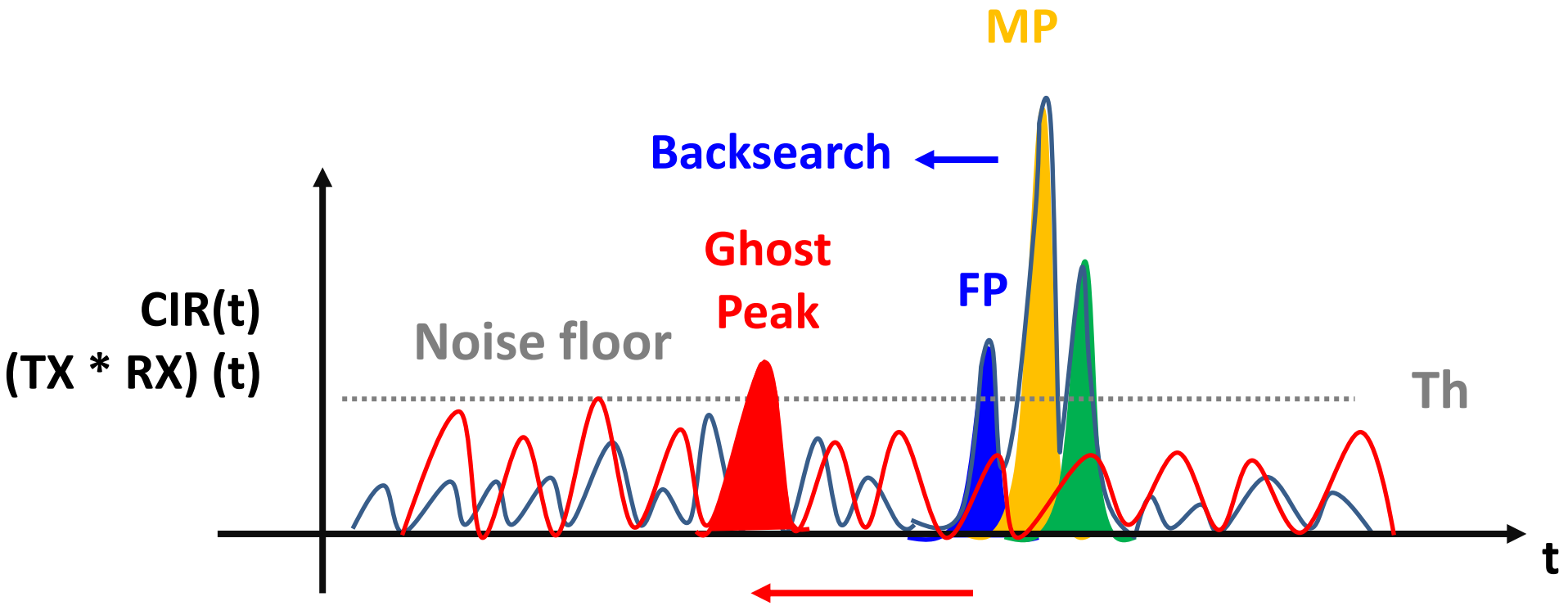


Earlier arrival time => distance reduction

Ghost Peak: summary of main results

Main Victim: Apple U1

Secondary victim: Apple, NXP, Qorvo

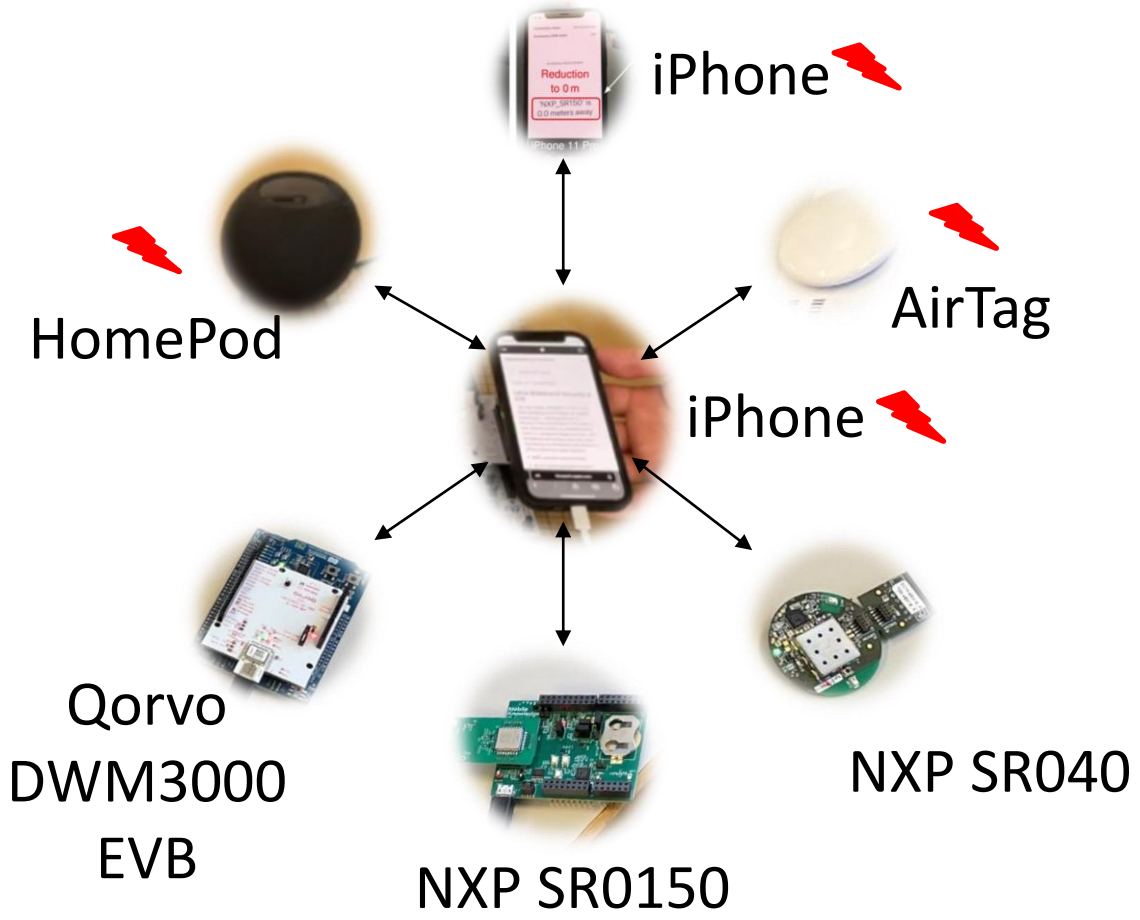
Attacker: Qorvo DWM3000EVB

Environment: real-world corridor

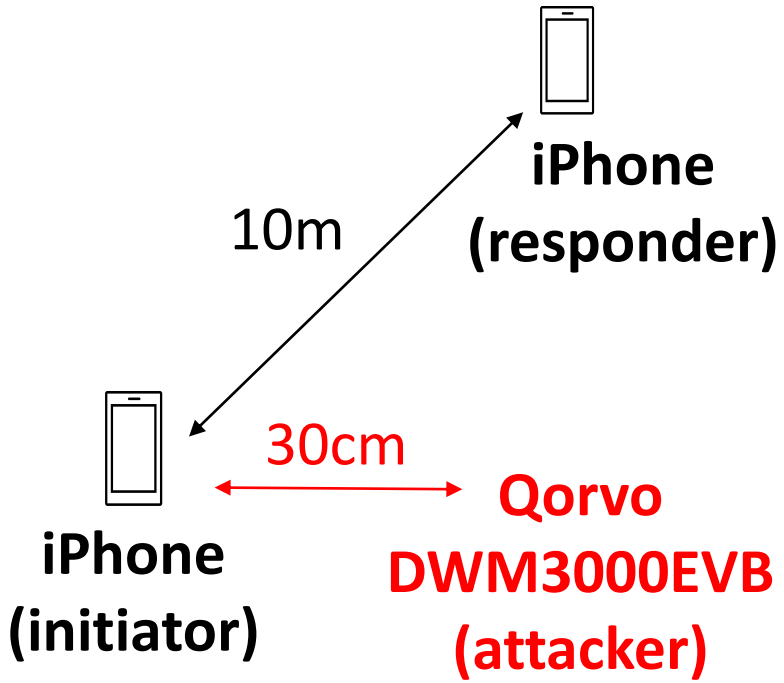
Max reduction: up to 12m reductions

Success rate : up to 4%

Check the paper for details



Ghost Peak: example of reduction



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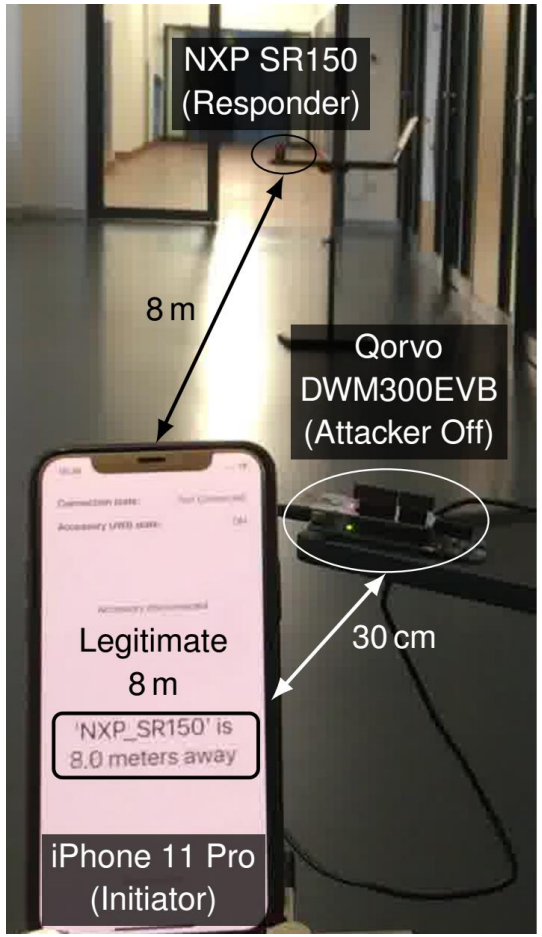

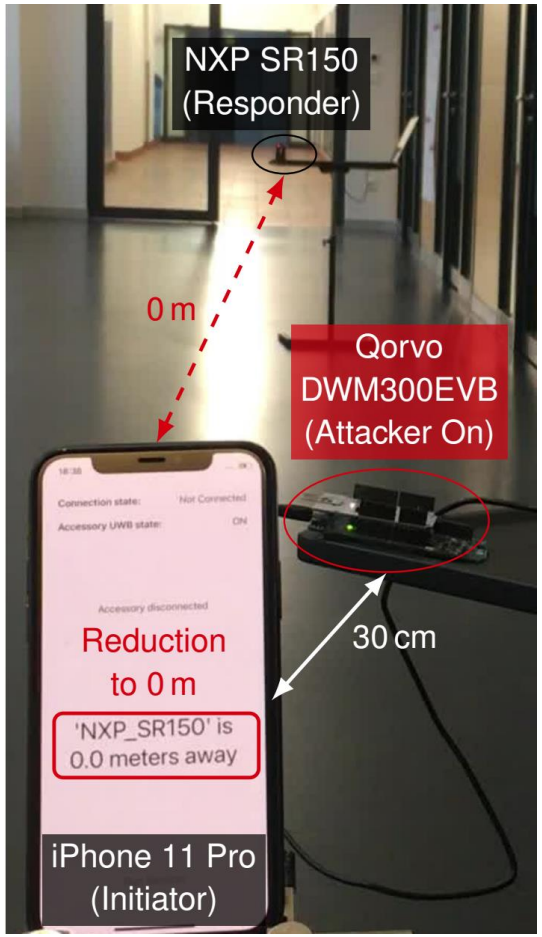

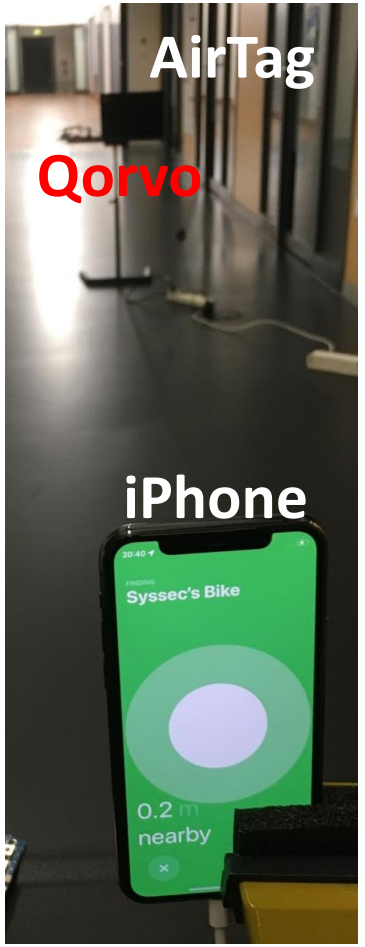

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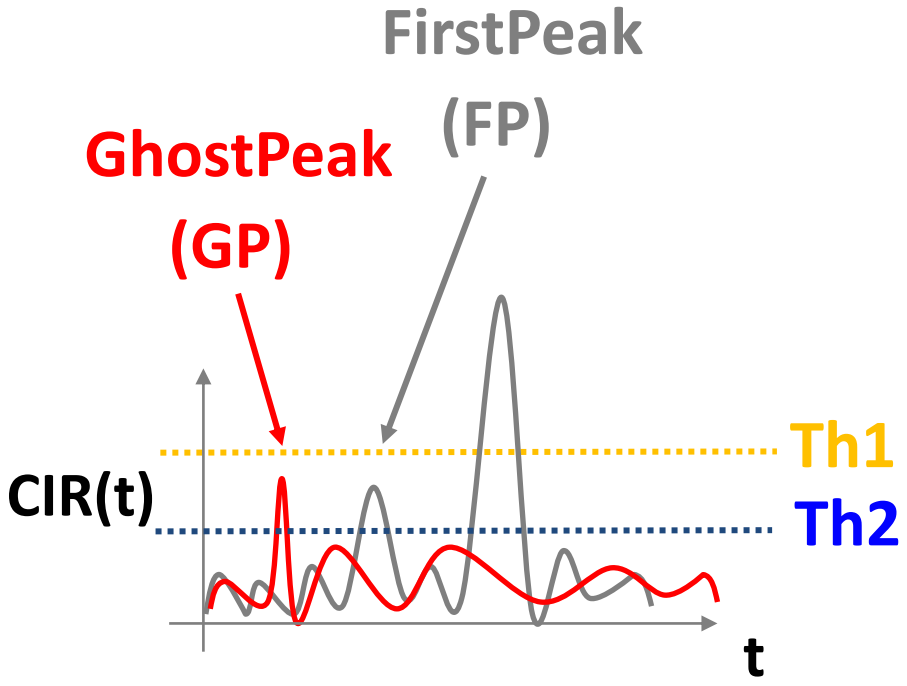
Root problems

1. Challenging problem

GP (random STS) vs. FP (right STS, low power)

Worsened by inter-pulse interference of HRP



*Possible designs and security/performance tradeoffs:
Singh et. Al, "Security analysis of IEEE 802.15.4z/HRP UWB time-of-flight distance measurement", ACM WiSec 2021

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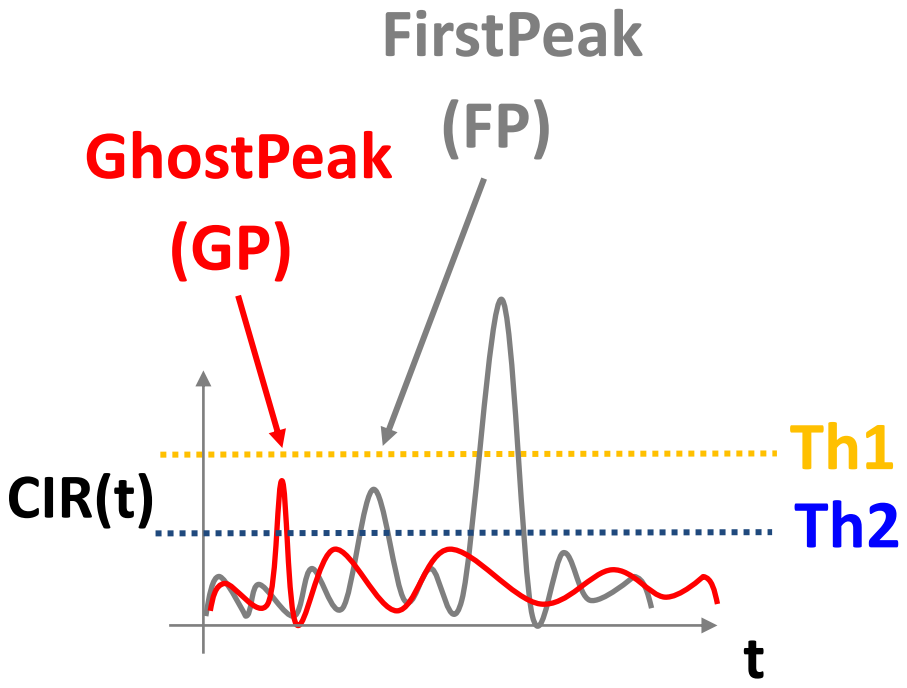
⇒ Security (Th1) vs. Performance (Th2)

⇒ Obscure implem. not defined in the standard*



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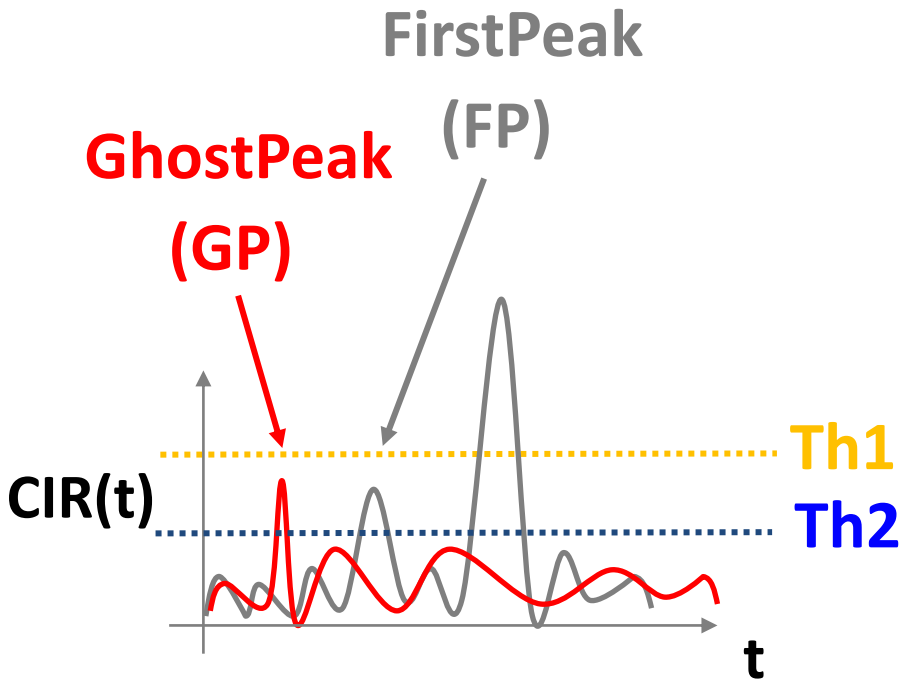
3. Lack of provable security

⇒ Correlation peak to STS similarity?

⇒ STS length to security level / success rate? Vice-versa?

⇒ Effect of obscure implem. mitigations?



*Possible designs and security/performance tradeoffs:
Singh et. Al, "Security analysis of IEEE 802.15.4z/HRP UWB time-of-flight distance measurement", ACM WiSec 2021

Mitigations & Future Work

Tuning some "Knobs" here and there + Testing

- Check preamble and STS consistency, Increase the threshold, …
- Test some configurations, …

Root problems not really solved
Attacking is "harder", by how much?

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Root problems not really solved
Attacking is "harder", by how much?

New IEEE standard (work in progress)

Tries to solve the problem at its root

- Decouple functionality/performance from security validation
- Provable security level in number of bits, open security design
- Best of HRP (perf.) and LRP (security)

Takeaway

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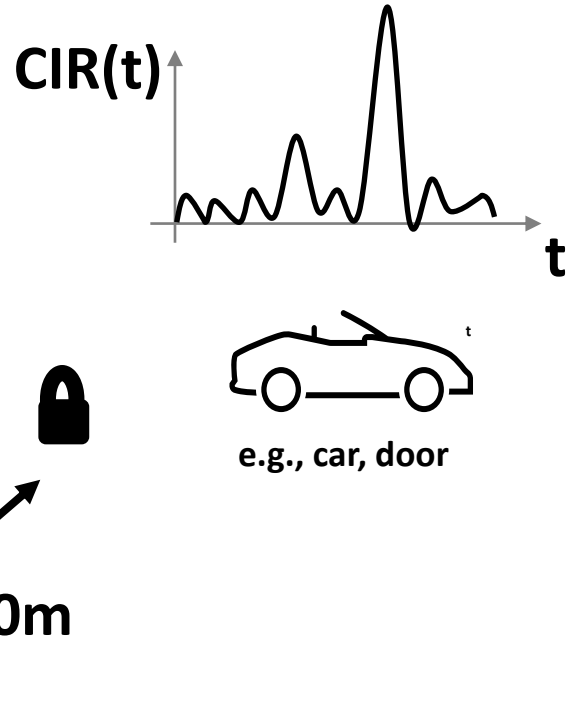

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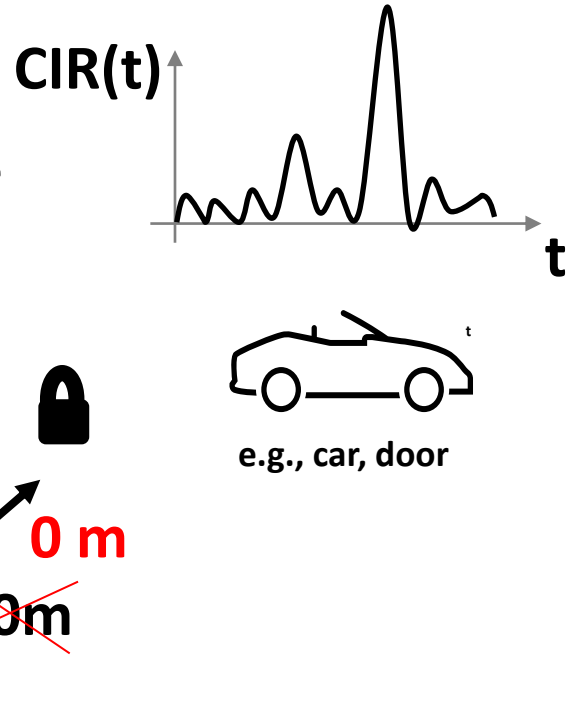

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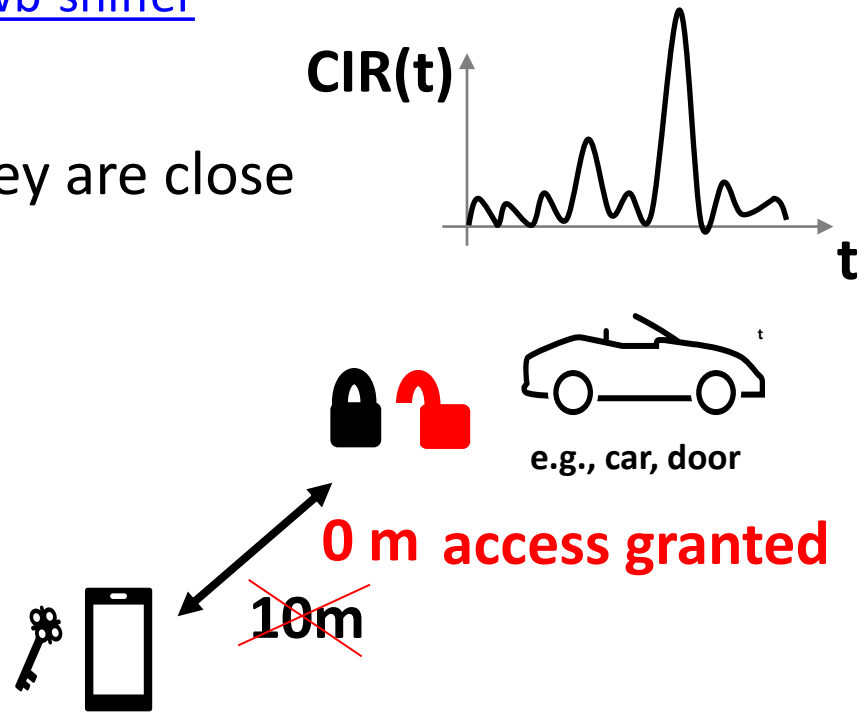

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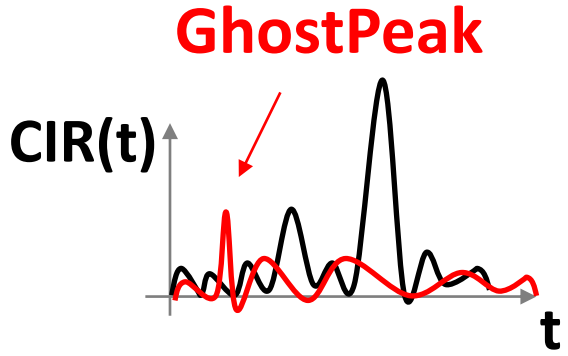

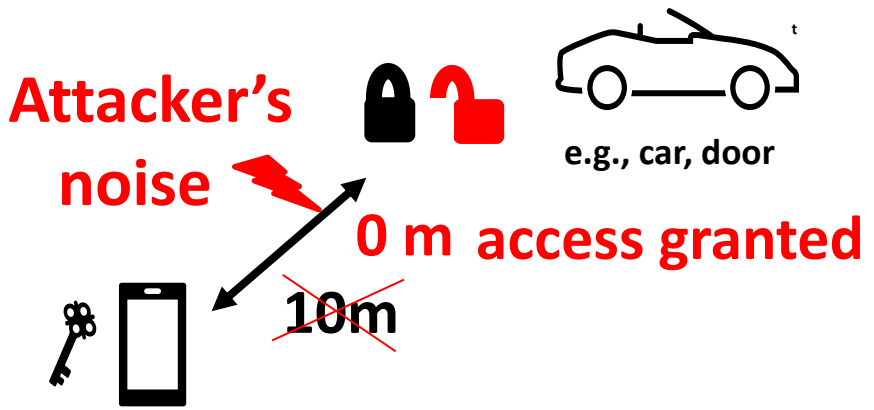

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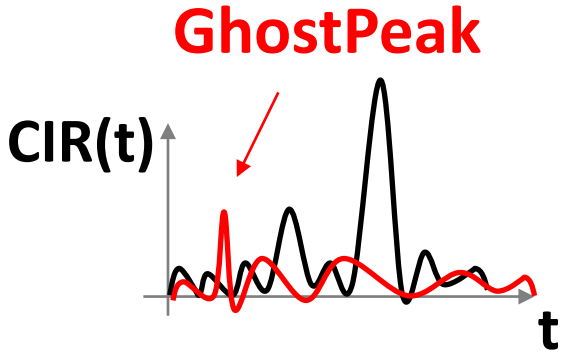

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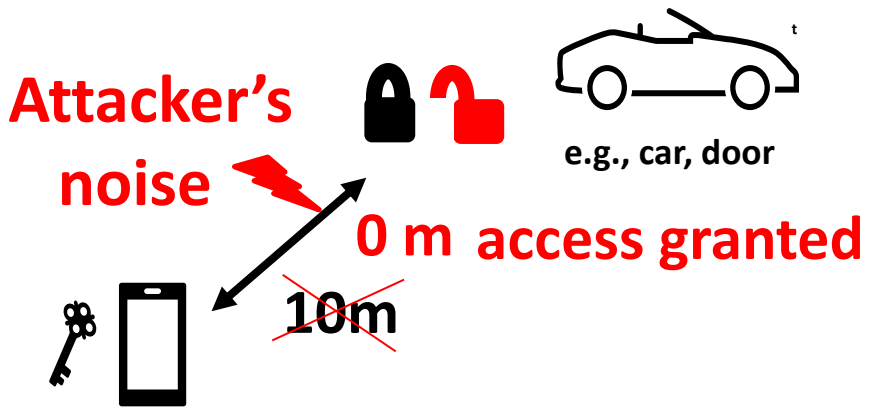

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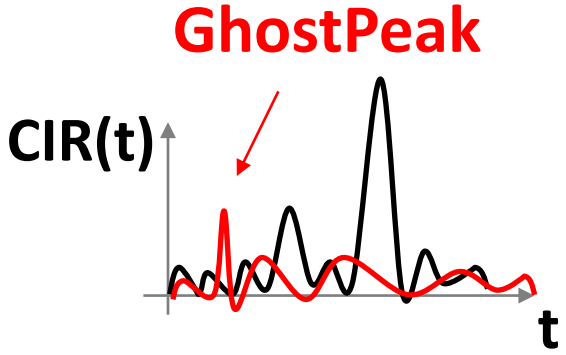

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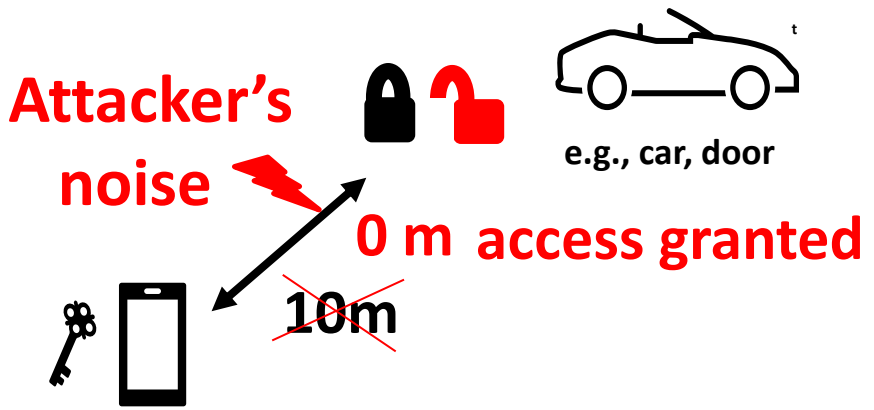

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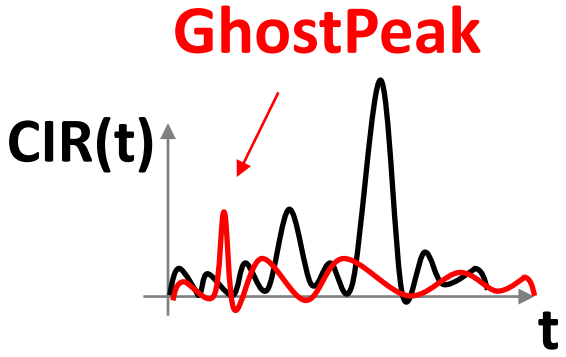

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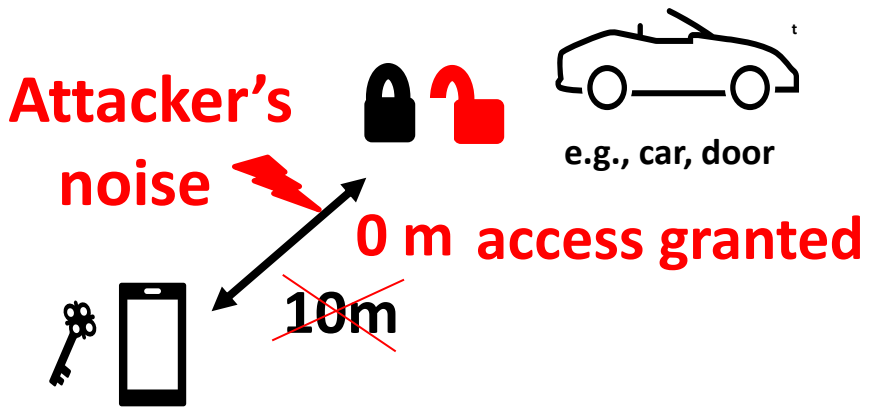

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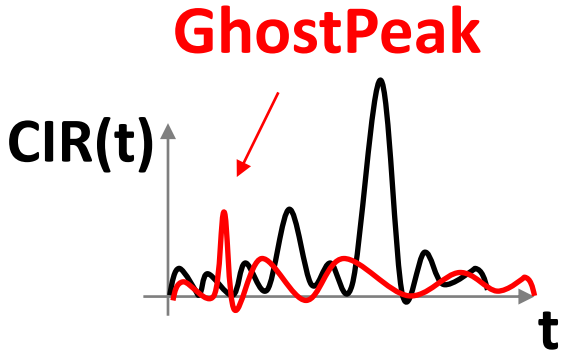

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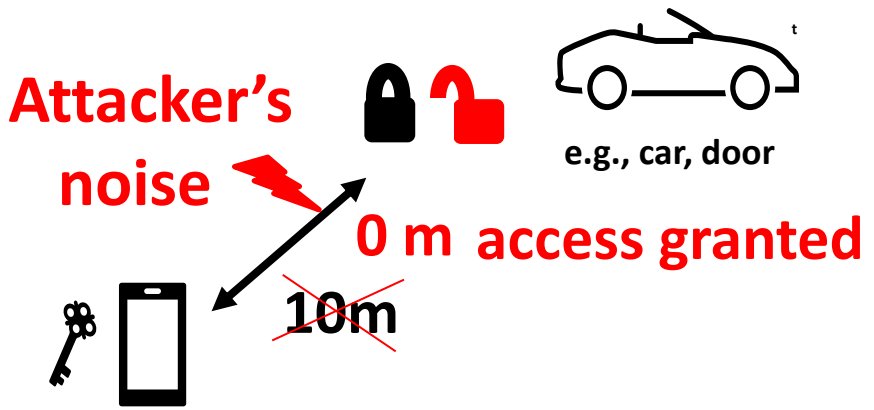

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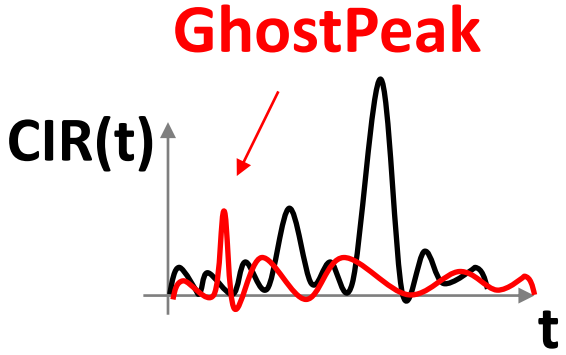

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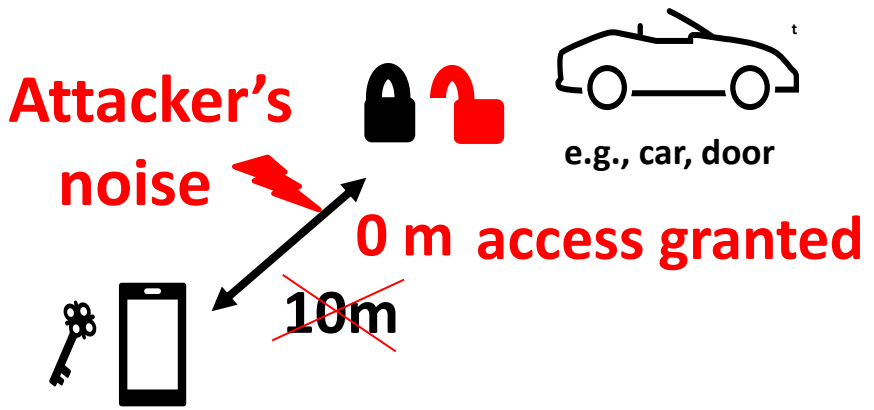

Thank you! Questions?

Backup Slides

Ghost Peak: main results

Primary Victim	Secondary Victim	Roles	Initiation	Max. Reduction	Success Rate
HomePod mini (Apple U1)	iPhone (Apple U1)	Init./Resp.	Proximity*	9.01 m	2.10 %
iPhone (Apple U1)	iPhone (Apple U1)	Init./Resp.	Developer choice**	12.45 m	4.08 %
AirTag (Apple U1)	iPhone (Apple U1)	Init./Resp.	User interaction	9.09 m	4.25 %
iPhone (Apple U1)	Tag (NXP SR040)	Resp./Init.	Developer choice**	4.80 m	1.87 %
iPhone (Apple U1)	Tag (NXP SR150)	Init./Resp.	Developer choice**	9.68 m	2.15 %
iPhone (Apple U1)	Tag (Qorvo DWM3000)	Init./Resp.	Developer choice**	8.13 m	3.09 %

Acknowledgements

This research has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program under grant agreement No 726227. This research has received funding from the Swiss National Science Foundation under NCCR Automation, grant agreement 51NF40_180545. This project has been partially funded by Fondation Botnar. This work has been co-funded by the German Federal Ministry of Education and Research and the Hessen State Ministry for Higher Education, Research and the Arts within their joint support of the National Research Center for Applied Cybersecurity ATHENE.