DolphinAttack: Inaudible Voice Commands

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DolphinAttack

An approach to inject inaudible voice commands at voice controllable systems by exploiting the ultrasound channel and the vulnerability of the underlying audio hardware.

Voice Controllable System (VCS)

VCS = System + Speech Recognition

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Examples:

- Apple iPhone + Siri
- Google Nexus + Google Now
- Amazon Echo + Alexa
- ...

Voice Controllable System (VCS)

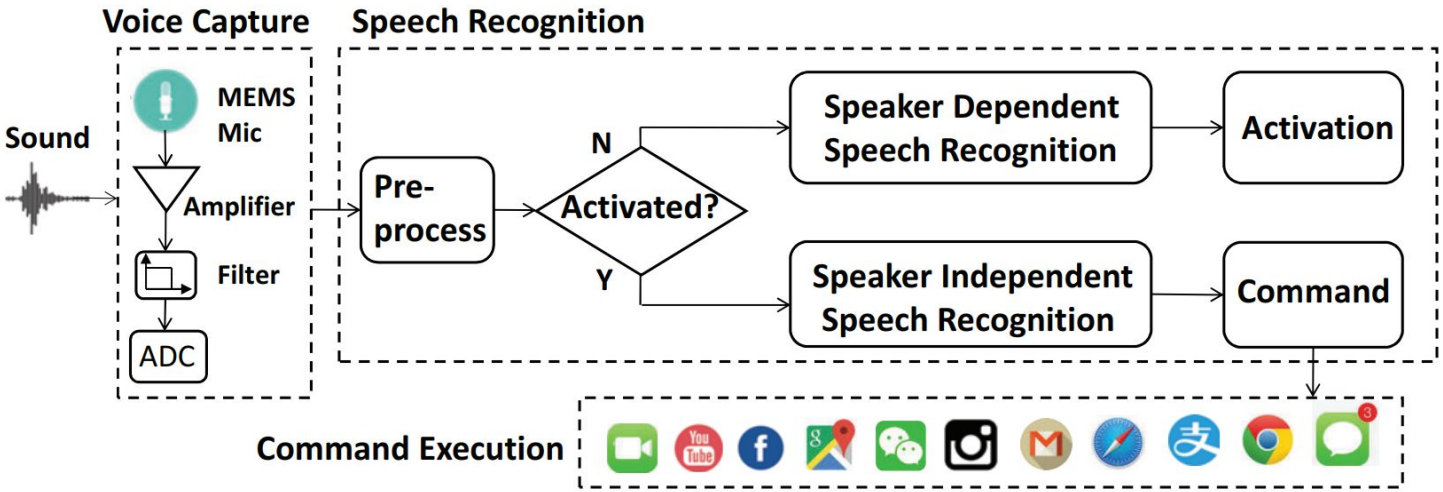
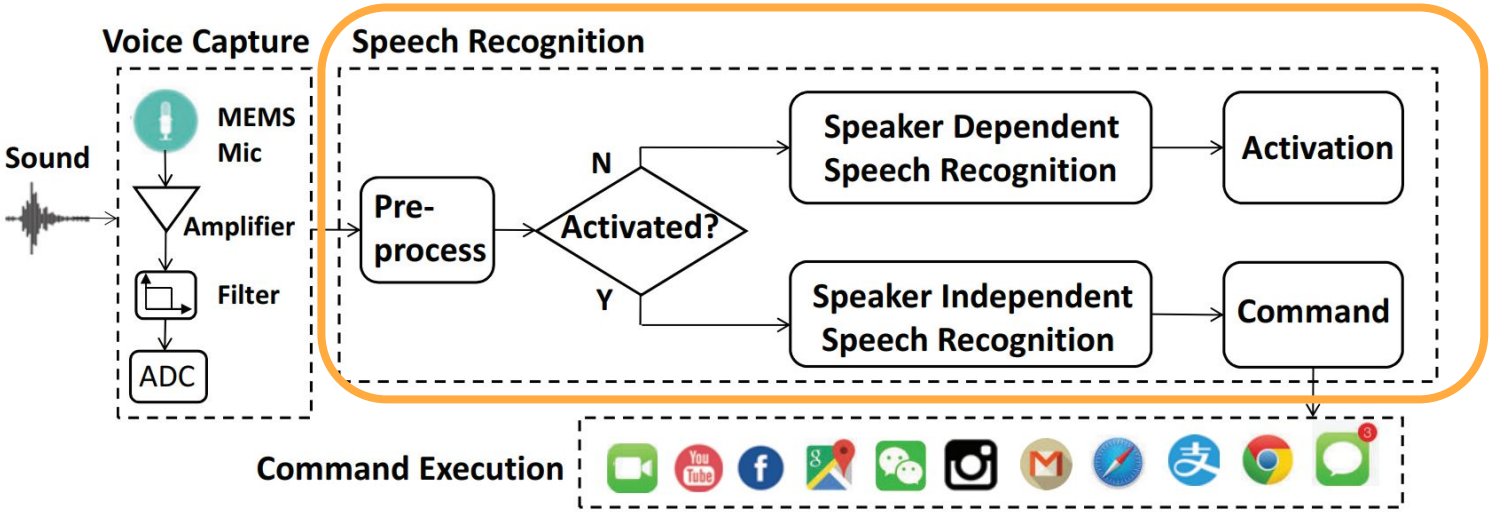


Figure 1: The architecture of a state-of-the-art VCS that can take voice commands as inputs and execute commands.

Voice Controllable System (VCS)



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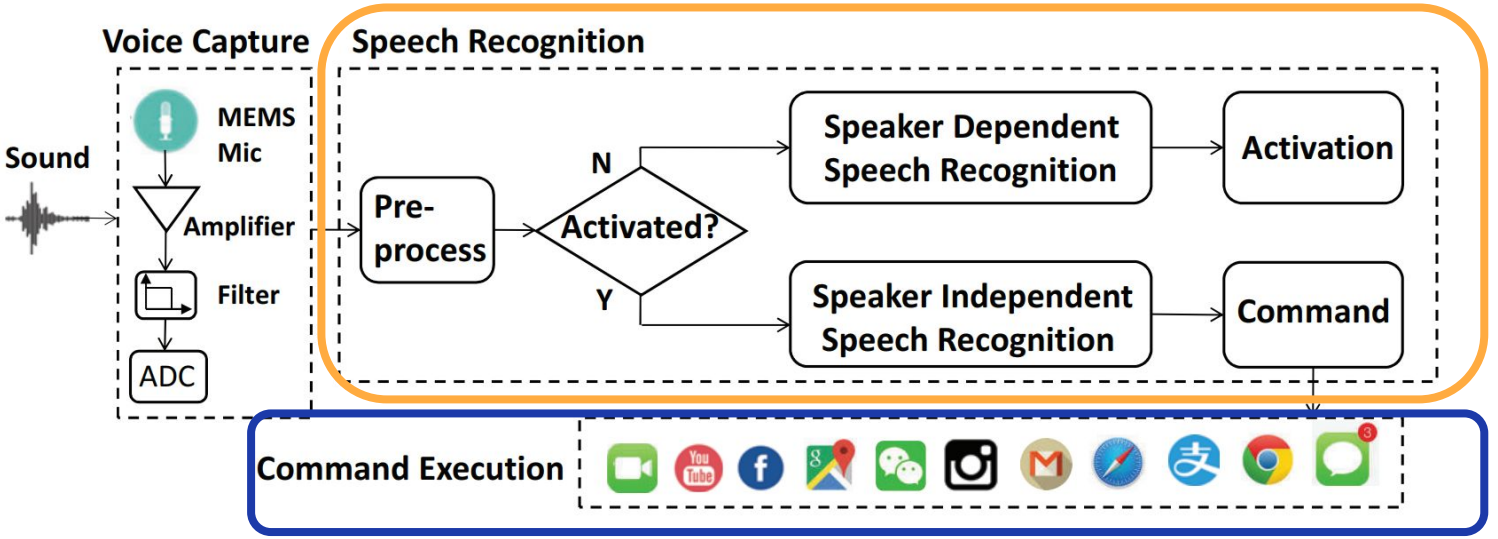
Voice Controllable System (VCS)

Machine Learning Attacks



Malware

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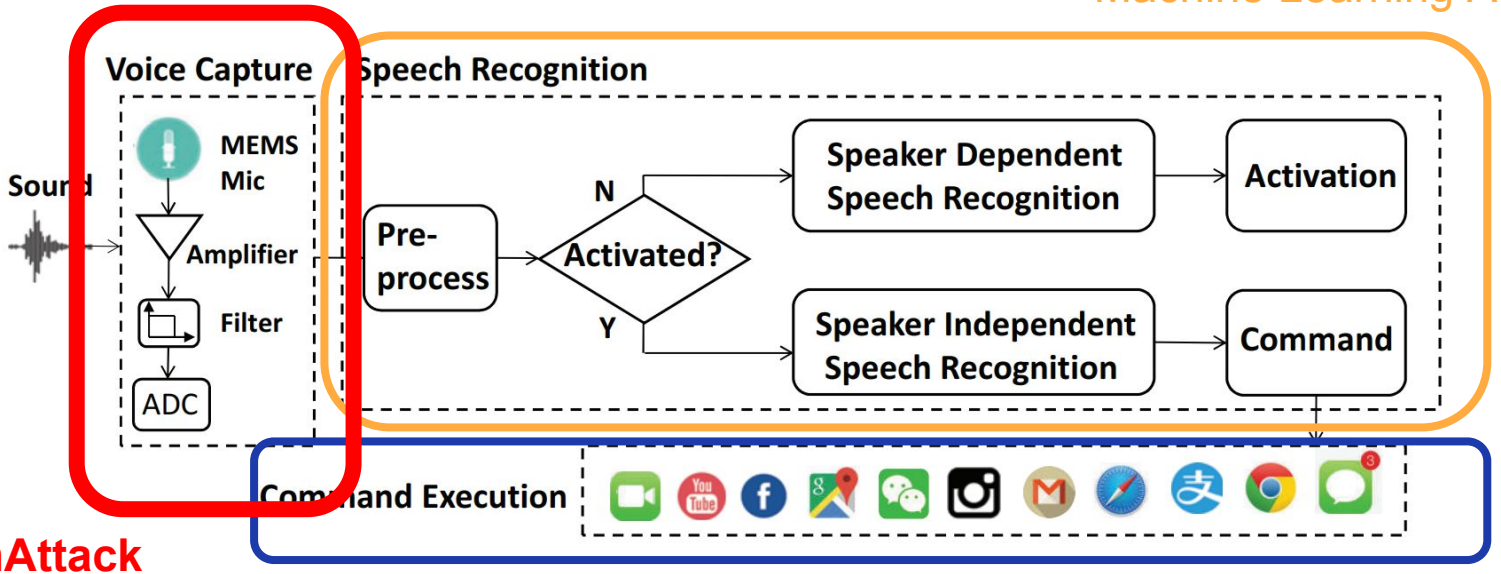
Voice Controllable System (VCS)

Machine Learning Attacks

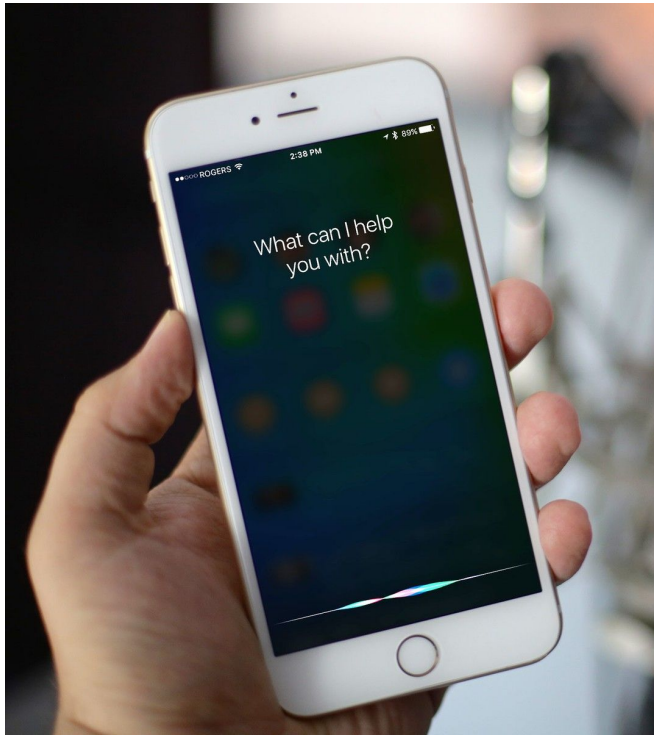


DolphinAttack

Malware

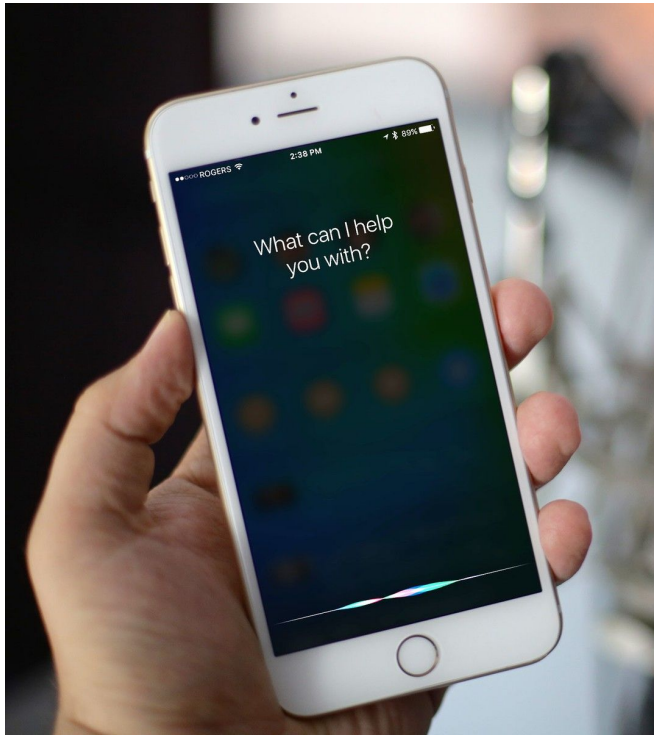
Figure 1: The architecture of a state-of-the-art VCS that can take voice commands as inputs and execute commands.

How can an attacker exploit this attack?



How can an attacker exploit this attack?

- Visiting a malicious website
- Spying
- Injecting fake information
- Denial of service
- … and more!



Fundamental Idea

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Modulate the low-frequency voice signal (baseband) on an ultrasonic carrier, and demodulate the modulated voice signals at the receiver…

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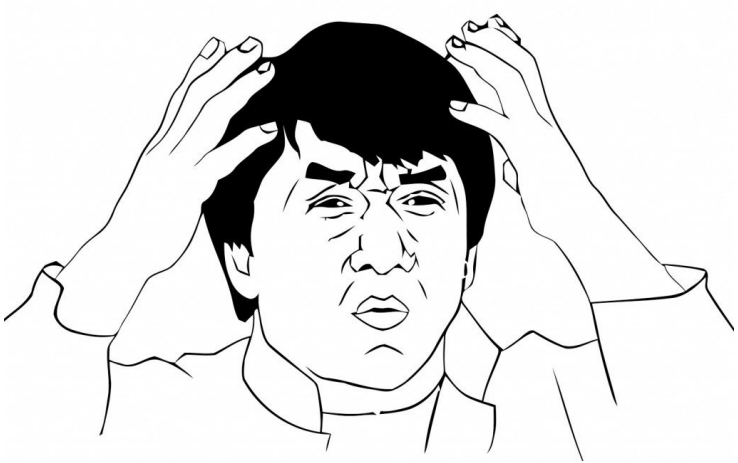

Categories of Sound Waves

- Infrasonic waves
  - $f < 20$ Hz
- Audible sound waves
  - $f = 20$ Hz – 20 kHz
- Ultrasonic waves
  - $f > 20$ kHz

(Amplitude) Modulation

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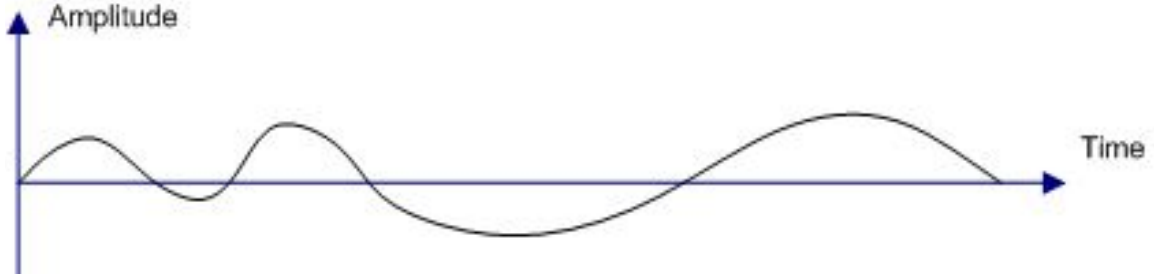
Low-Frequency
Voice Signal
(Baseband)

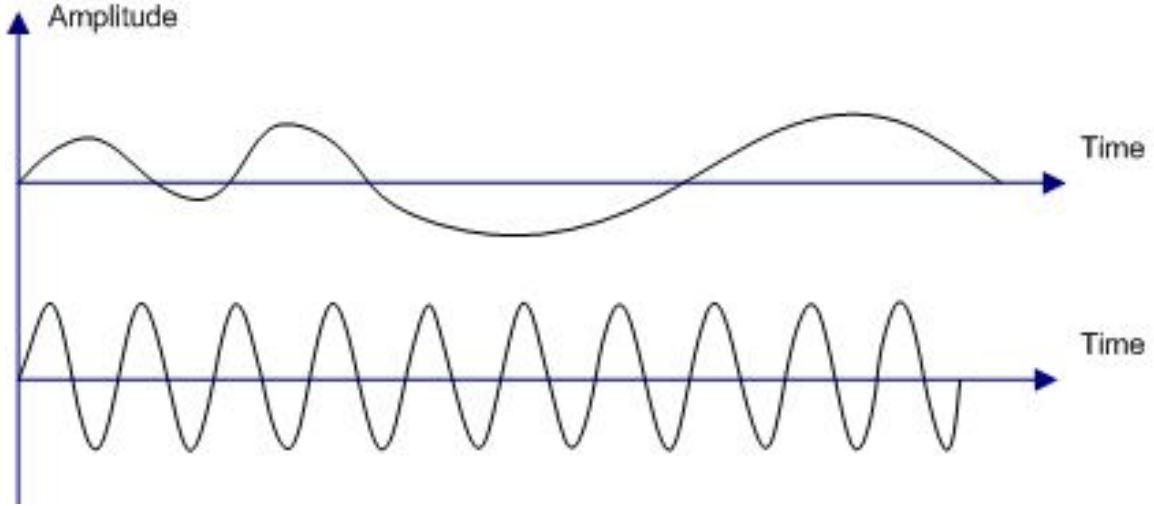


(Amplitude) Modulation

Low-Frequency
Voice Signal
(Baseband)

+

Ultrasonic
(high-frequency)
Carrier Signal



(Amplitude) Modulation

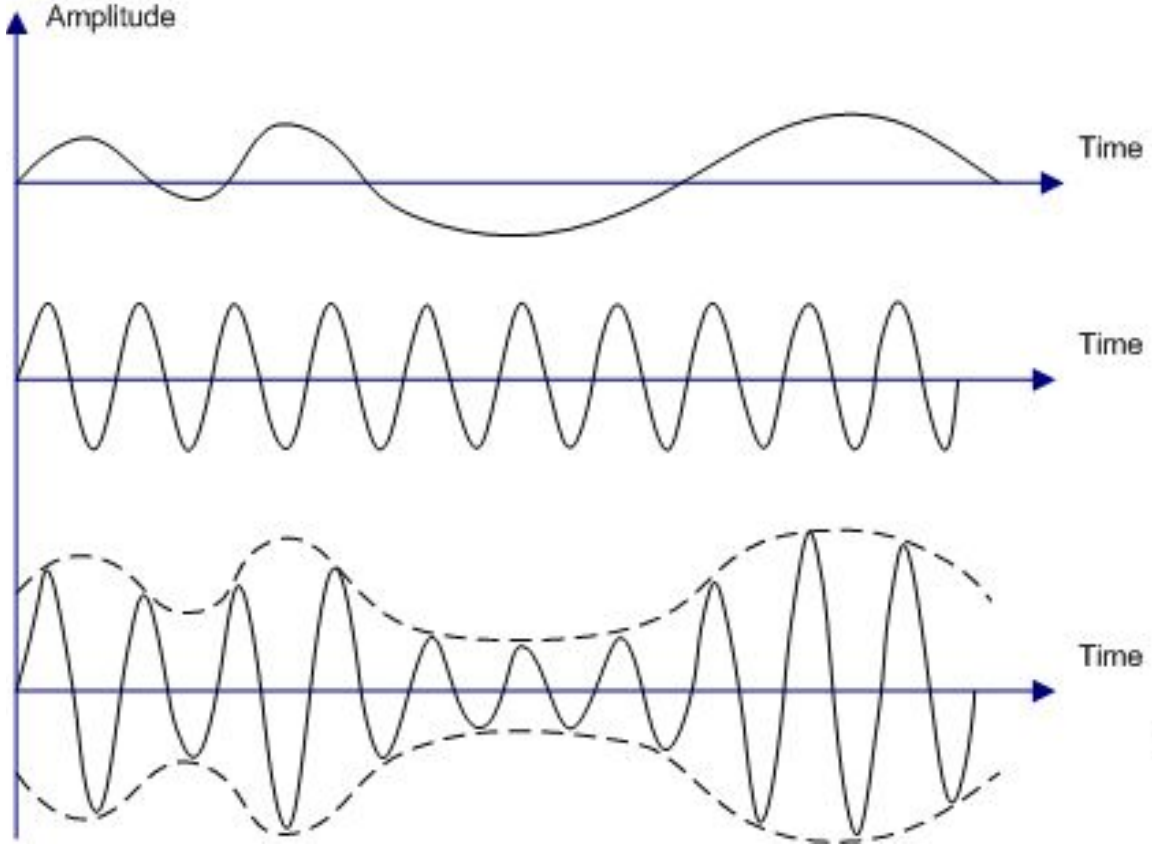
Low-Frequency
Voice Signal
(Baseband)

+

Ultrasonic
(high-frequency)
Carrier Signal

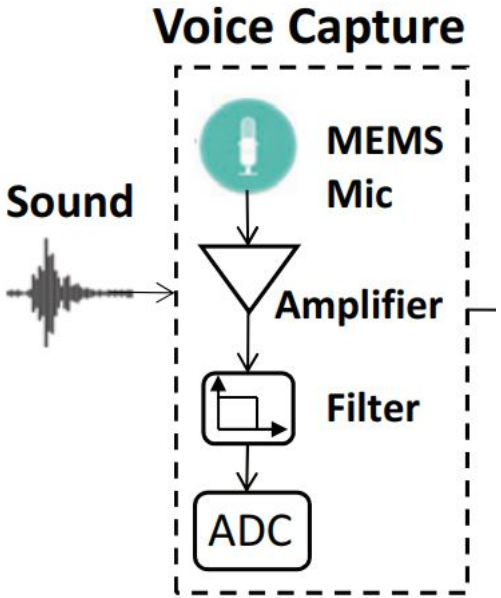
=

Modulated
(high-frequency)
Voice Signal



How to recover the voice signal?

- Exploit the electrical characteristics of microphones and amplifiers...



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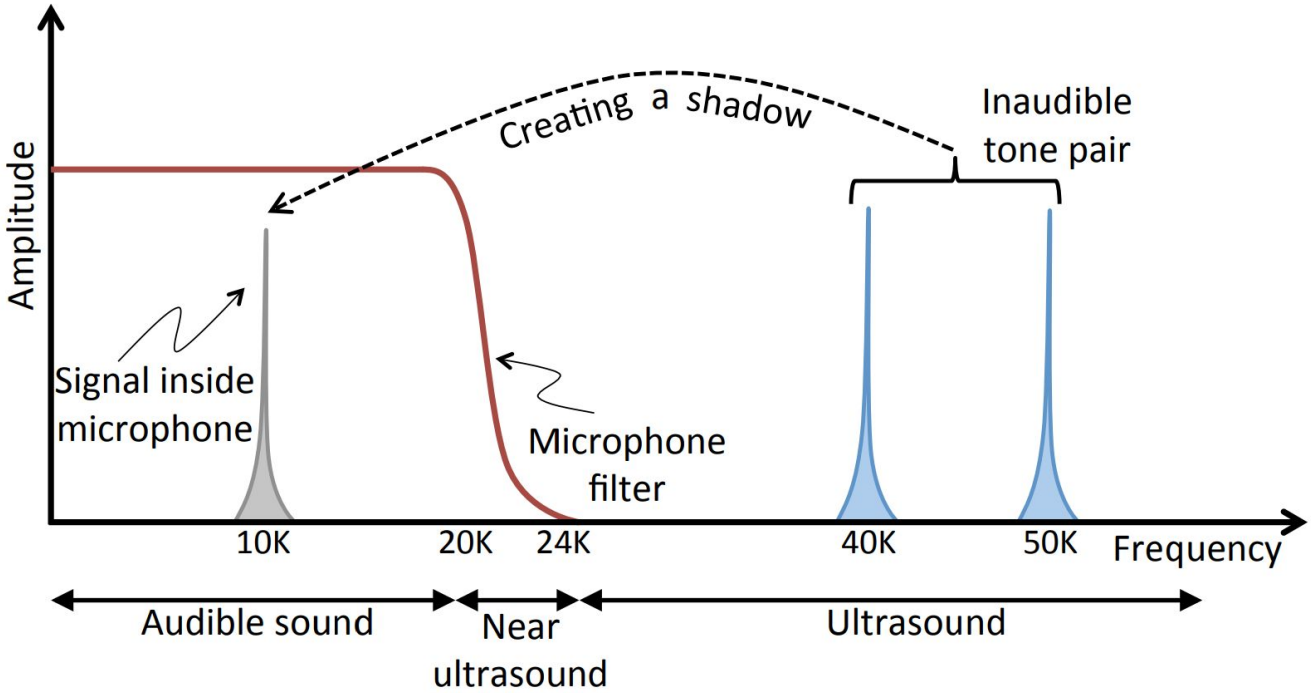
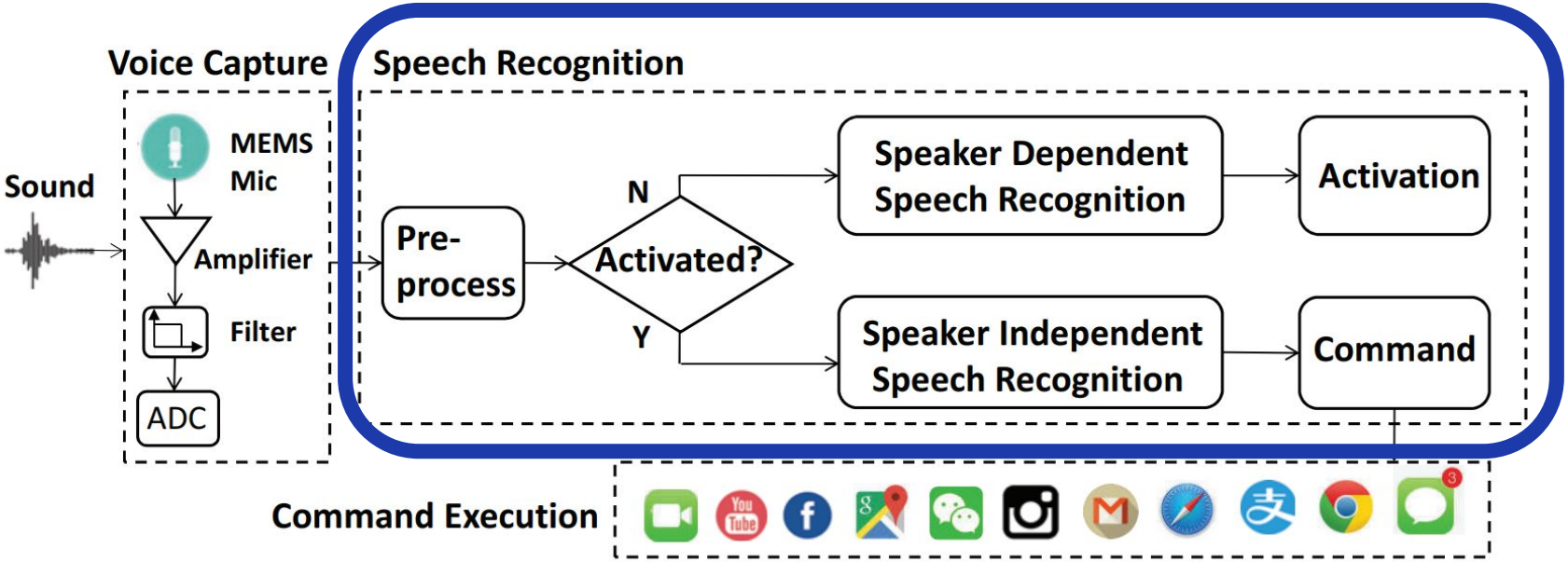


Nirupam Roy, Haitham Hassanieh, and Romit Roy Choudhury. 2017. BackDoor: Making Microphones Hear Inaudible Sounds. In Proceedings of the 15th Annual International Conference on Mobile Systems, Applications, and Services (MobiSys '17). ACM, New York, NY, USA, 2-14. DOI: https://doi.org/10.1145/3081333.3081366

Voice Command Generation



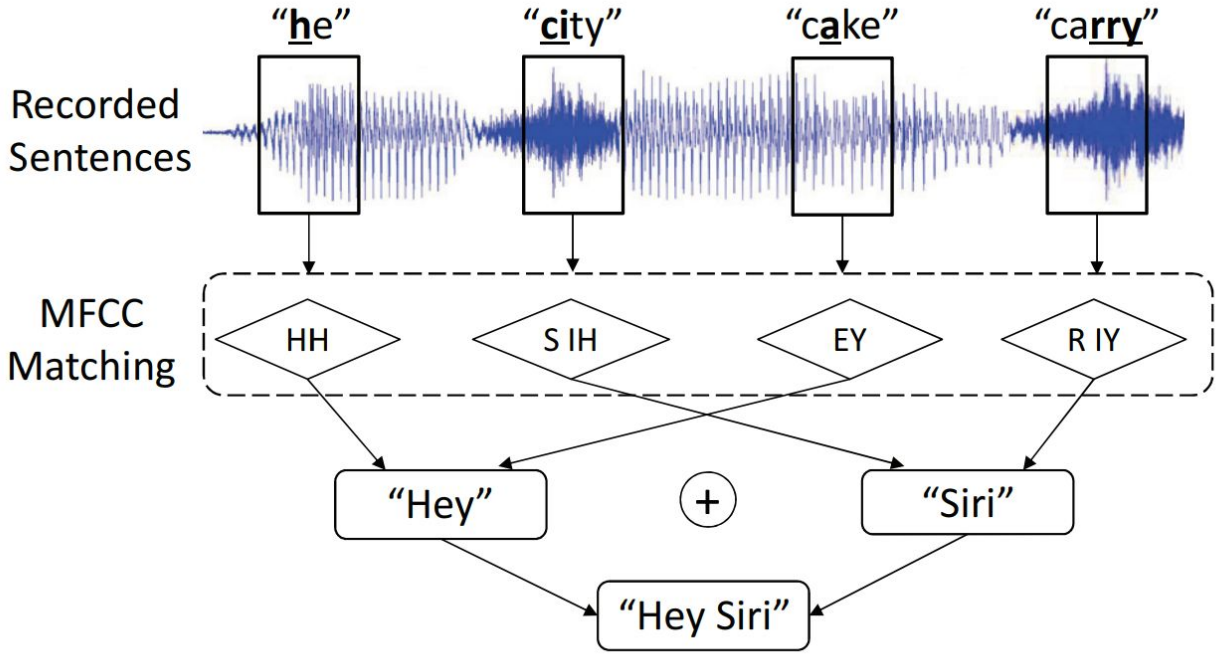
Activation Command Generation - Approach #1

Text-to-speech based brute force

TTS Systems	voice type #	# of successful types	
		Call 12..90	Hey Siri
Selvy Speech [51]	4	4	2
Baidu [8]	1	1	0
Sestek [45]	7	7	2
NeoSpeech [39]	8	8	2
Innoetics [59]	12	12	7
Vocalware [63]	15	15	8
CereProc [12]	22	22	9
Acapela [22]	13	13	1
Fromtexttospeech [58]	7	7	4

Activation Command Generation - Approach #2

Concatenative synthesis (with a few voice recordings)



Threat Model

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- Attacker has no access to the target device

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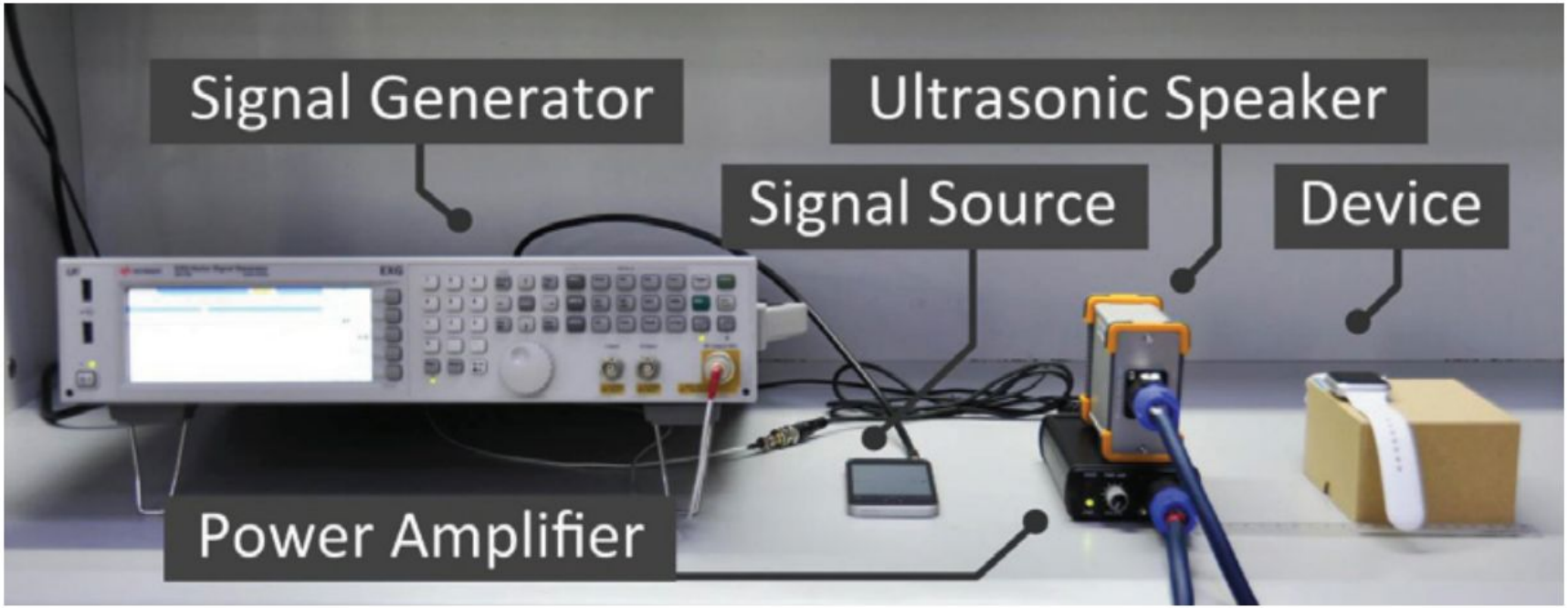
- No owner interaction (e.g. unlocking the screen)
- Attacker will use inaudible voice commands
  - Ultrasound (f > 20 kHz)
- Attacker can acquire the required equipment (e.g. speakers designed for transmitting ultrasound)

Experiment Setup (Feasibility Analysis)



Demonstration

Targeted Systems

Table 2: The list of systems and voice commands being tested in Tab. 3.

Attack	Device/System	Command
Recognition	Phones & Wearable	*Call 1234567890*
Recognition	iPad	*FaceTime 1234567890*
Recognition	MacBook & Nexus 7	*Open dolphinattack.com*
Recognition	Windows PC	*Turn on airplane mode*
Recognition	Amazon Echo	*Open the back door*
Recognition	Vehicle (Audi Q3)	*Navigation* *
Activation	Siri	*Hey Siri*
Activation	Google Now	*Ok Google*
Activation	Samsung S Voice	*Hi Galaxy*
Activation	Huawei HiVoice	*Hello Huawei* *
Activation	Alexa	*Alexa*

* The command is spoken in Chinese due to the lack of English support on these devices.

Manuf.	Model	OS/Ver.	SR System	Attacks		Max Dist. (cm)	
				Recog.	Activ.	Recog.	Activ.
Apple	iPhone 4s	iOS 9.3.5	Siri	√	√	175	110
Apple	iPhone 5s	iOS 10.0.2	Siri	√	√	7.5	10
Apple	iPhone SE	iOS 10.3.1	Siri	√	√	30	25
			Chrome	√	N/A	16	N/A
Apple	iPhone SE †	iOS 10.3.2	Siri	√	√	21	24
Apple	iPhone 6s *	iOS 10.2.1	Siri	√	√	4	12
Apple	iPhone 6 Plus *	iOS 10.3.1	Siri	×	√	–	2
Apple	iPhone 7 Plus *	iOS 10.3.1	Siri	√	√	18	12
Apple	watch	watchOS 3.1	Siri	√	√	111	164
Apple	iPad mini 4	iOS 10.2.1	Siri	√	√	91.6	50.5
Apple	MacBook	macOS Sierra	Siri	√	N/A	31	N/A
LG	Nexus 5X	Android 7.1.1	Google Now	√	√	6	11
Asus	Nexus 7	Android 6.0.1	Google Now	√	√	88	87
Samsung	Galaxy S6 edge	Android 6.0.1	S Voice	√	√	36.1	56.2
Huawei	Honor 7	Android 6.0	HiVoice	√	√	13	14
Lenovo	ThinkPad T440p	Windows 10	Cortana	√	√	58	8
Amazon	Echo *	5589	Alexa	√	√	165	165
Audi	Q3	N/A	N/A	√	N/A	10	N/A

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Apple	iPhone SE	iOS 10.3.1	Siri	√	√	30	25
			Chrome	√	N/A	16	N/A
Apple	iPhone SE †	iOS 10.3.2	Siri	√	√	21	24
Apple	iPhone 6s *	iOS 10.2.1	Siri	√	√	4	12
Apple	iPhone 6 Plus *	iOS 10.3.1	Siri	×	√	–	2
Apple	iPhone 7 Plus *	iOS 10.3.1	Siri	√	√	18	12
Apple	watch	watchOS 3.1	Siri	√	√	111	164

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Apple	iPhone 6 Plus *	iOS 10.3.1	Siri	×	√	–	2
Apple	iPhone 7 Plus *	iOS 10.3.1	Siri	√	√	18	12
Apple	watch	watchOS 3.1	Siri	√	√	111	164

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Apple	iPhone 6 Plus *	iOS 10.3.1	Siri	×	√	–	2
Apple	iPhone 7 Plus *	iOS 10.3.1	Siri	√	√	18	12
Apple	watch	watchOS 3.1	Siri	√	√	111	164

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Audi	Q3	N/A	N/A	√	N/A	10	N/A

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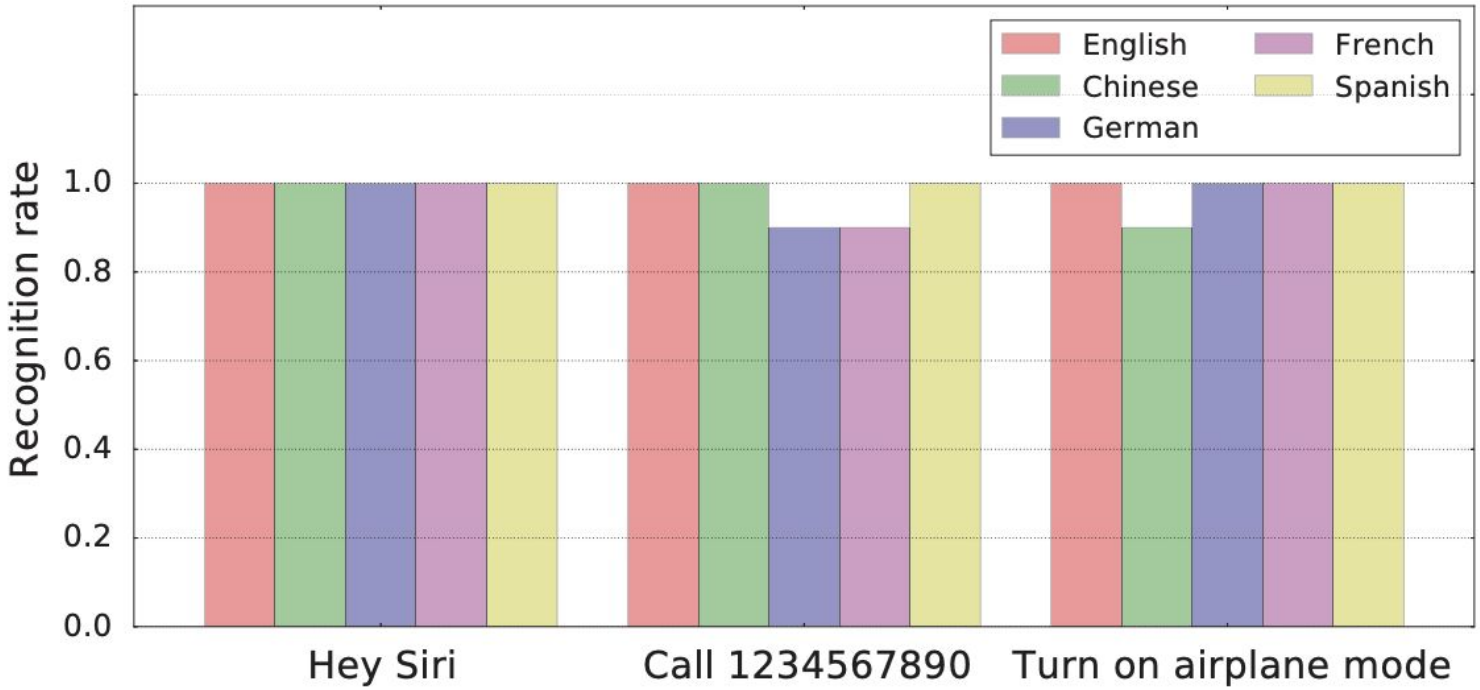
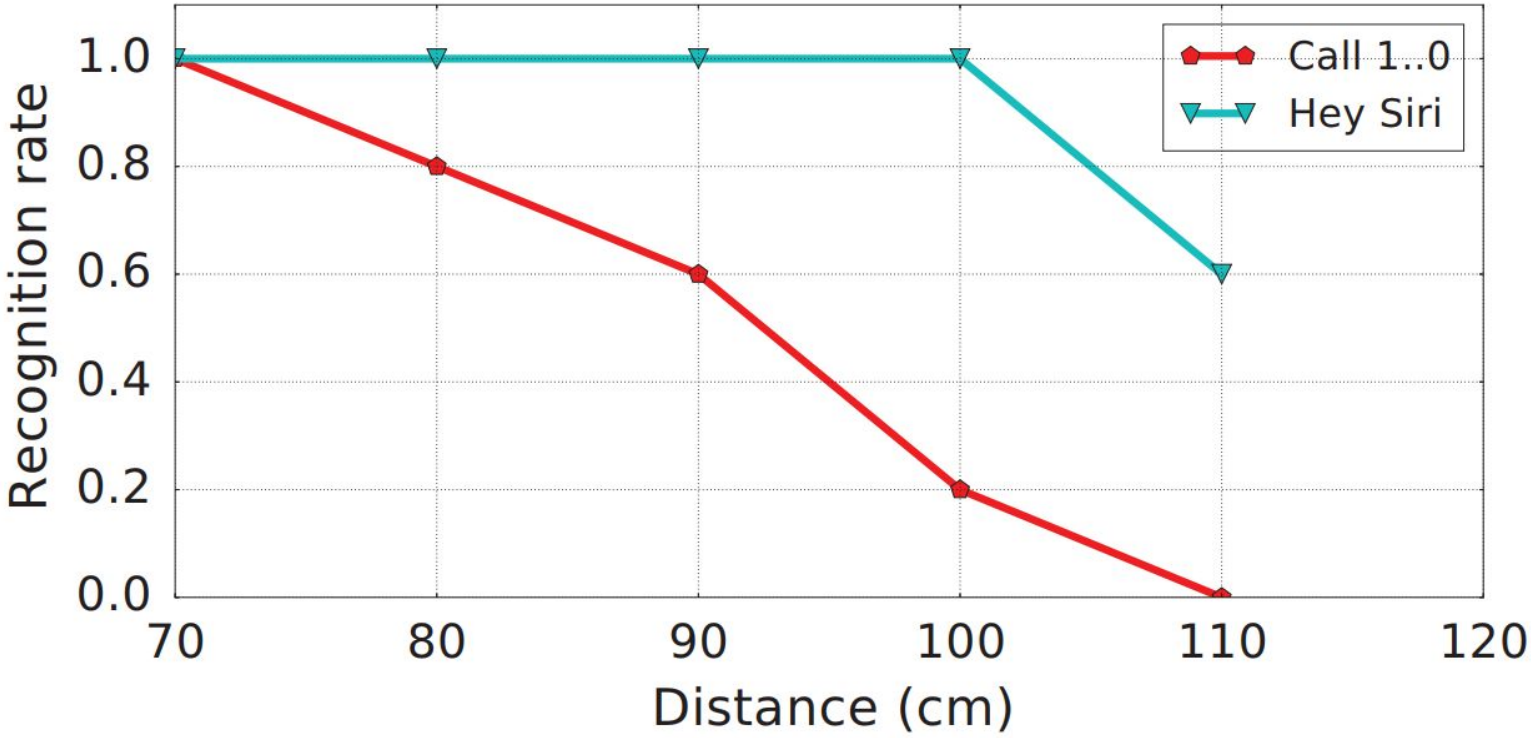
Influence of Languages (Apple Watch)



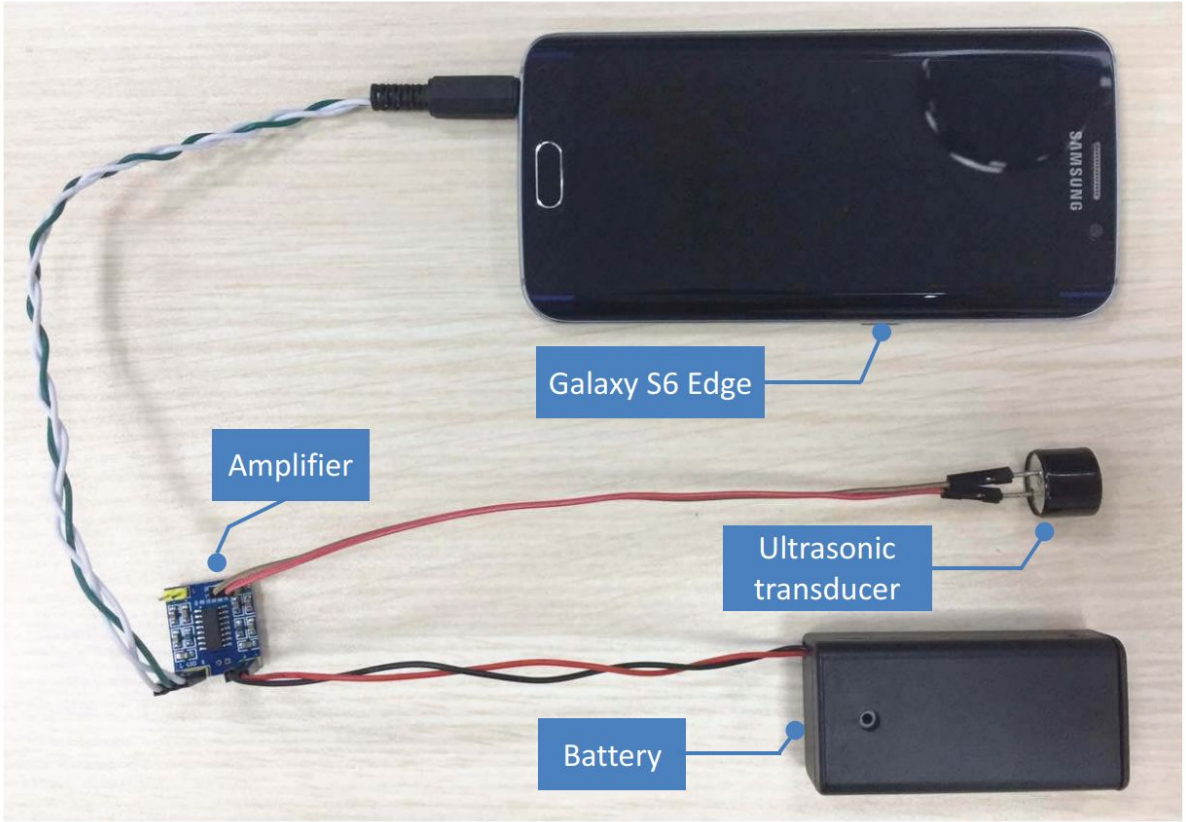
Impact of Background Noises (Apple Watch)

Scene	Noises (dB)	Recognition rates	
		Hey Siri	Turn on airplane mode
Office	55–65	100%	100%
Cafe	65–75	100%	80%
Street	75–85	90%	30%

Impact of Attack Distances (Apple Watch)



Great! What about something more portable?



Portable Setup

"Turn on airplane mode" (without amplifier)

Table 5: Portable device attack results. Attacking an Apple watch using a Galaxy S6 Edge smartphone that is 2 cm away.

f_c (kHz)	20	21	22	23	24
Word recognition rate	80%	100%	16%	100%	0%
Sentence recognition rate	80%	100%	0%	100%	0%

Portable Setup

*With the amplifier module, the maximum distance of effective attacks is increased to **27 cm**.*

Proposed Defenses

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- Hardware-based

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  - Microphone enhancement

Proposed Defenses

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  - Microphone enhancement
  - Inaudible voice command cancellation

Proposed Defenses

- Hardware-based
  - Microphone enhancement
  - Inaudible voice command cancellation
- Software-based

Proposed Defenses

- Hardware-based
  - Microphone enhancement
  - Inaudible voice command cancellation
- Software-based
  - Distinguish modulated voice commands and genuine ones using machine learning (e.g. SVM)

Thank you!

Questions?