Audio-WiFi: A cross-interface framework of communication for smartphones

Presenter: **Mostafa Uddin**

About me

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- 3rd year PhD student (started Fall 2011)
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- B.Sc. In BUET(Bangladesh University of Engineering & Technology)
- Worked in HP Labs(Palo Alto, CA.)
- Worked as SE for 4 years.

Area of Research

- Mobile Computing
  - Mobile sensing
  - Localization
  - Smart Home
  - Mobile health
- Wireless Network
  - WiFi energy efficiency
  - Mobile Traffic Analysis
  - Traffic Classification
  - WLAN virtualization
  - Mobile SDN extension
  - Multi-interface

Motivation

Wi-Fi is one of the prominent network interface
for smart devices

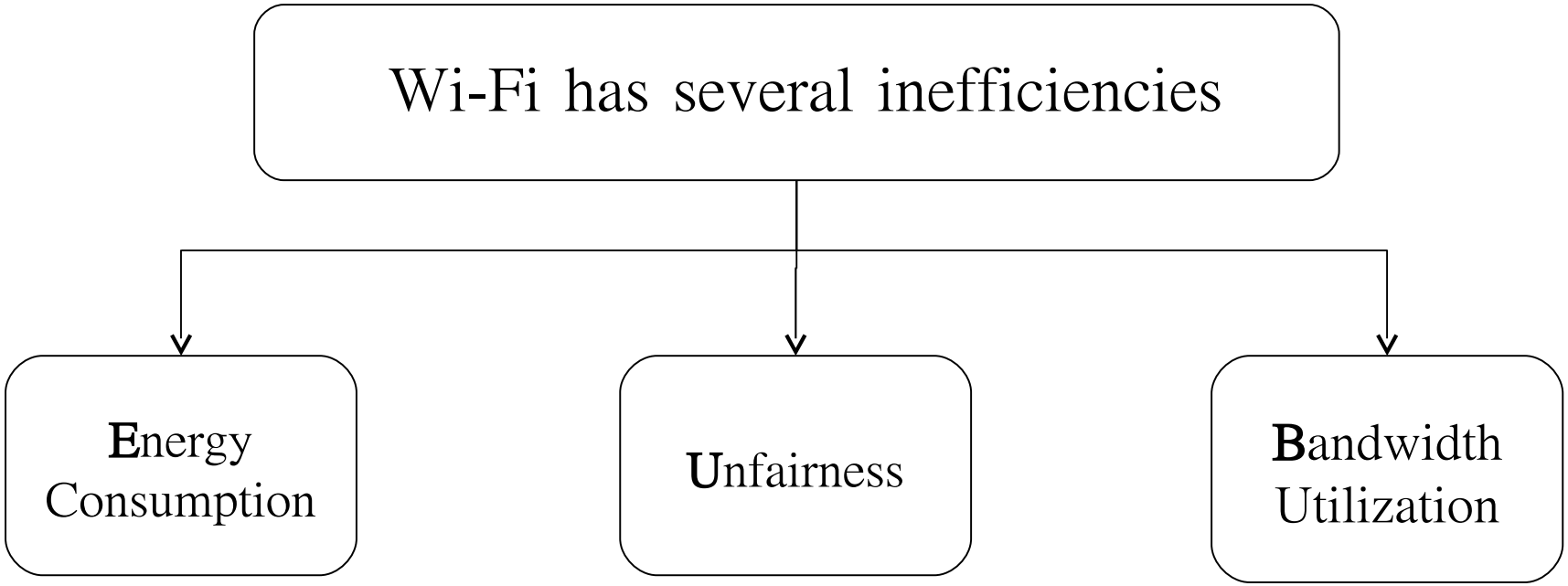
Low cost + **H**igh throughput + **L**arge range + **U**biquitous

More Motivation

Direct communication (e.g. Wi-Fi Direct, Wi-Fi IBSS) between Wi-Fi peer devices is increasing

Peer-to-peer applications(e.g. File sharing, multiplayer games, media streaming)

Problem

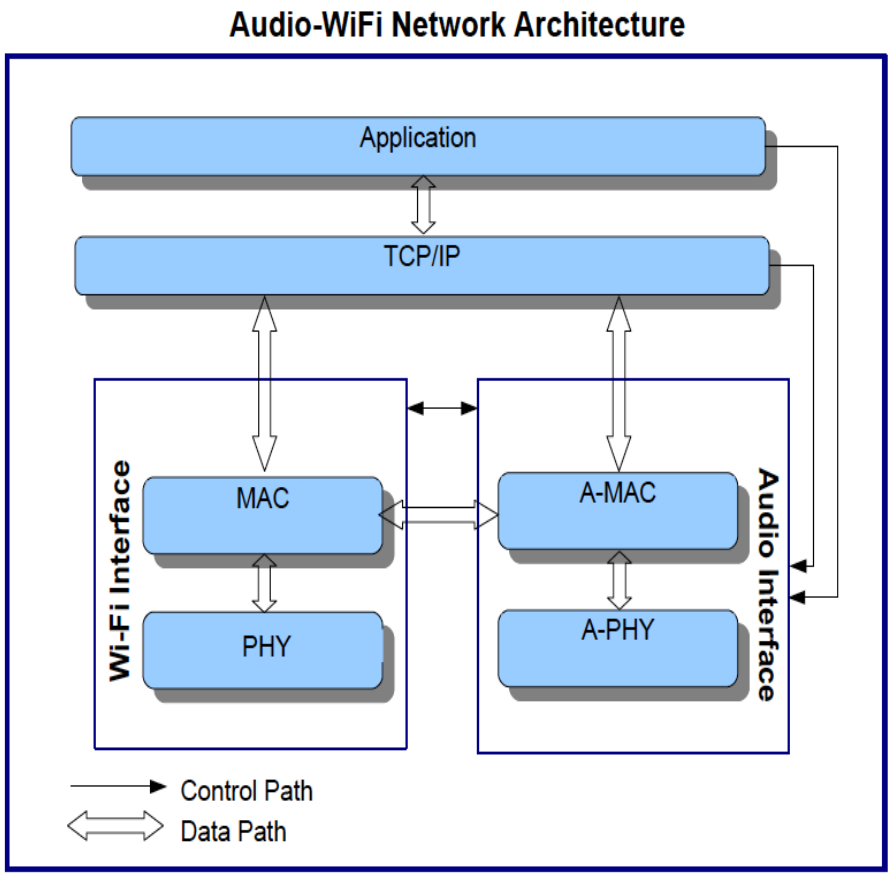

Wi-Fi has several inefficiencies
Energy Consumption
Unfairness
Bandwidth Utilization

Vision

Wi-Fi Interface + Audio Interface = Audio-WiFi

Augmenting the audio Interface(mic/speaker) with the Wi-Fi to enhance and optimize the data communication over Wi-Fi interface.

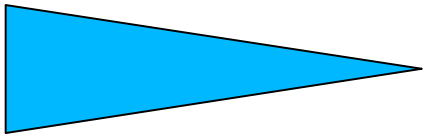
Audio-WiFi Architecture



- A-PHY: responsible for signal processing and signal TX/RX using speaker/microphone.
- A-MAC: responsible for generating/receiving the control frame over audio channel.
- Wi-Fi MAC and upper layer utilize the audio interface to send/receive control frames over(e.g. Beacon frame) using A-MAC layer.

Why Audio Interface

The audio interface is open and flexible in smart devices



Easy to integrate with the Wi-Fi interface at MAC and PHY layers

Introducing to A2PSM

Audio channel assisted Wi-Fi power saving mechanism for smart devices

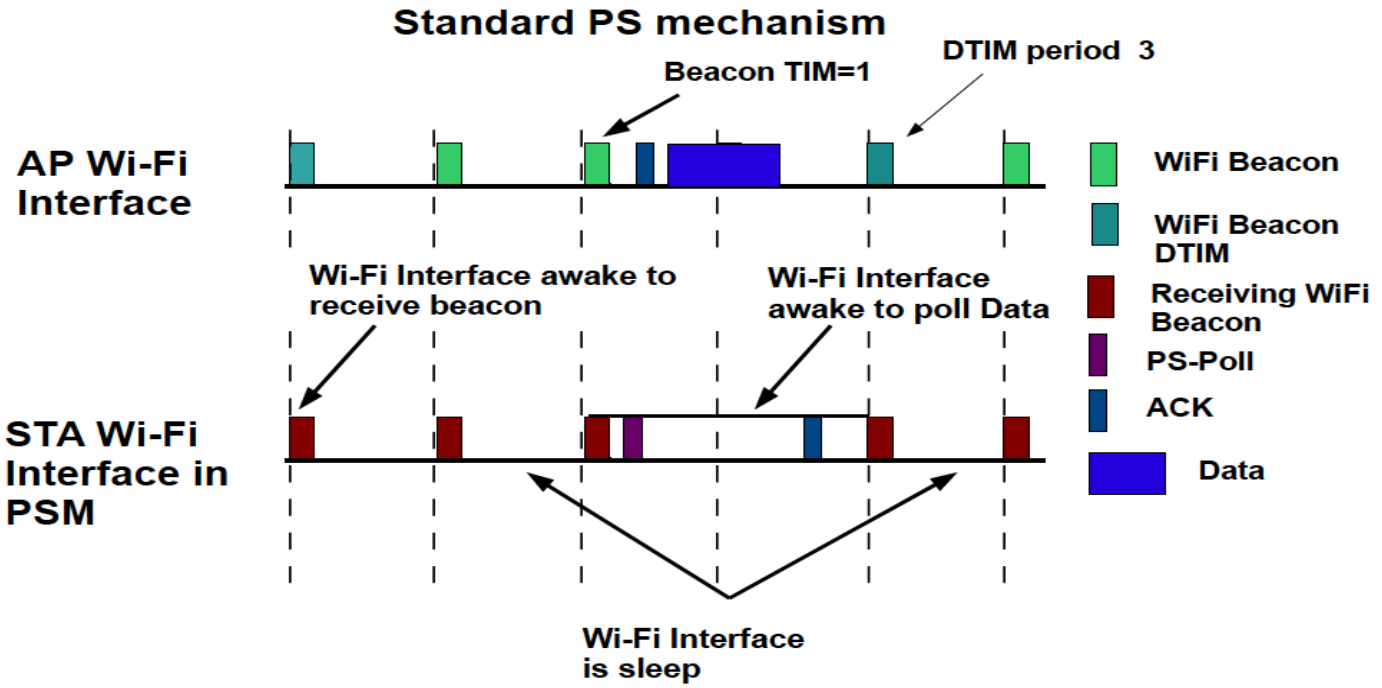
- We use the audio channel as a parallel channel.
- We exploit the audio frequency band beyond the human ear's perception.
- We use the off-the-shelf smart devices to implement the A2PSM scheme.

Use Cases

We assume both STA and AP has audio interface

- A2PSM focuses on Wi-Fi infrastructure mode.
- Wi-Fi Direct works more like Wi-Fi Infrastructure mode.

Power Management



- Wi-Fi interface has two power management modes: i) CAM and ii)PSM
- Commonly used Power Saving Mode(PSM) Static PSM (SPSM).
- In SPSM, the STA needs to wake up periodically even no data to exchange between AP and STA.

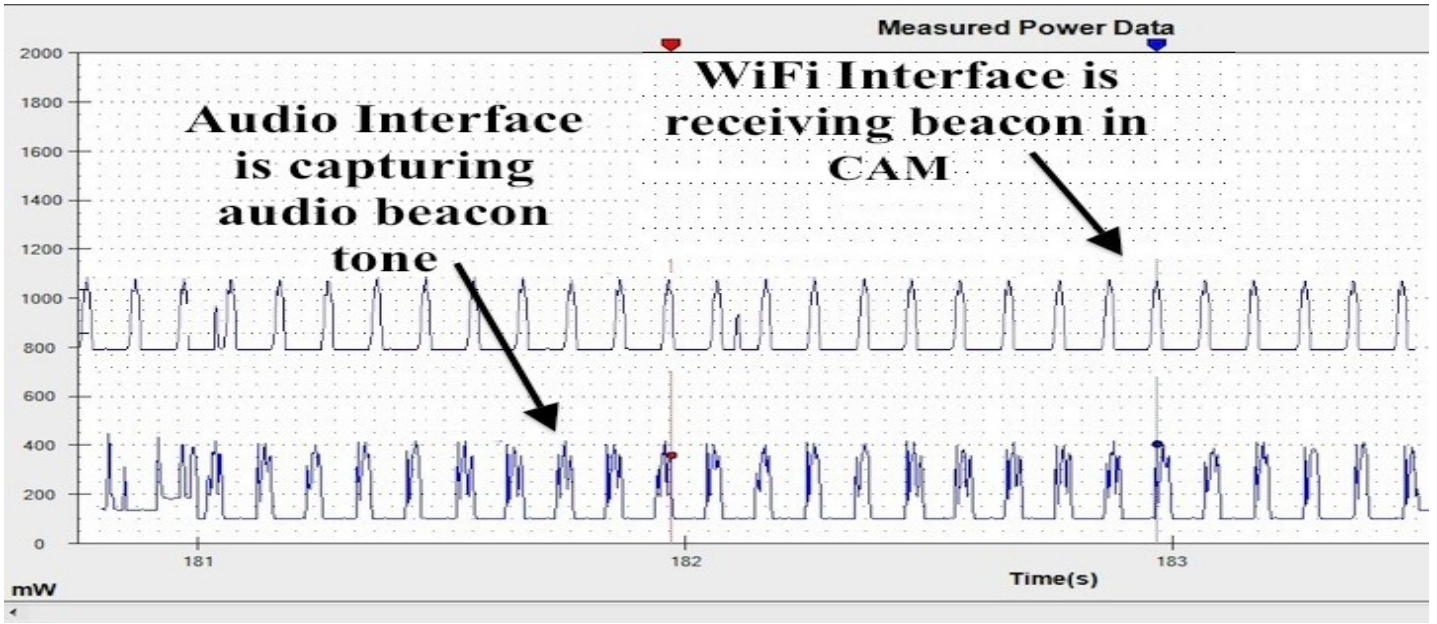
A2PSM: Core Concept

Use the audio interface as parallel channel to the Wi-Fi interface.

The STAs Wi-Fi interface remain sleep as long as no data to exchange between the AP and the STA.

While Wi-Fi interface remain sleep communication between AP and STA happens thru audio channel.

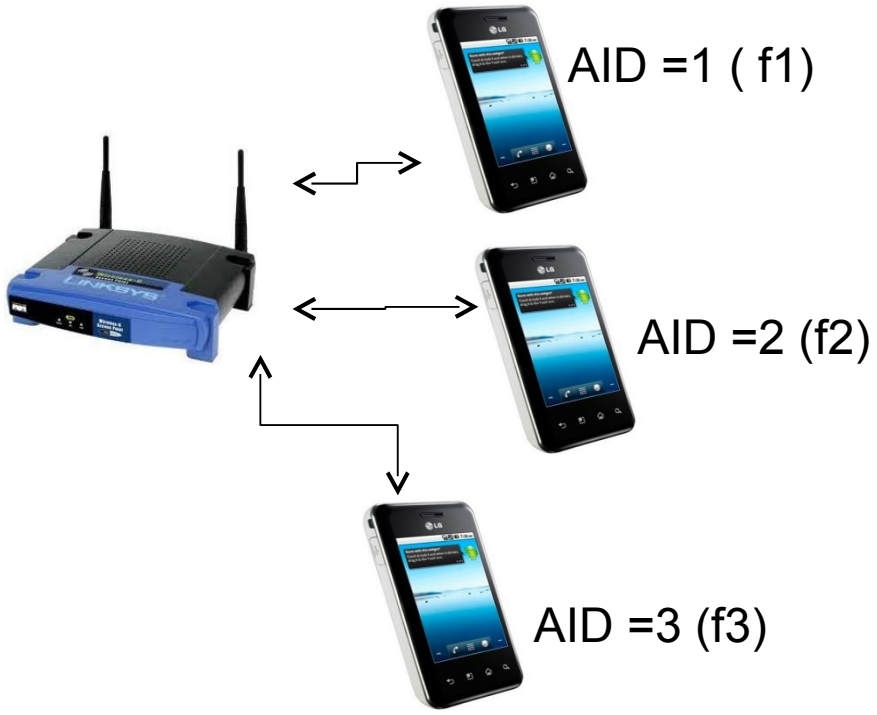
Power Consumption Comparison



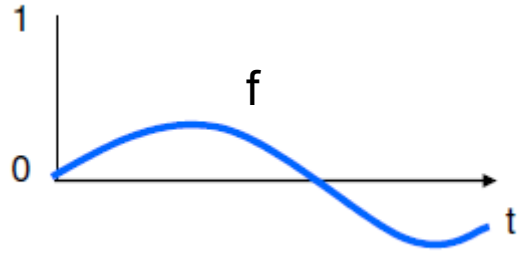
Wi-Fi interface consumes three times more power than the Audio interface.

Audio Beacon Tone

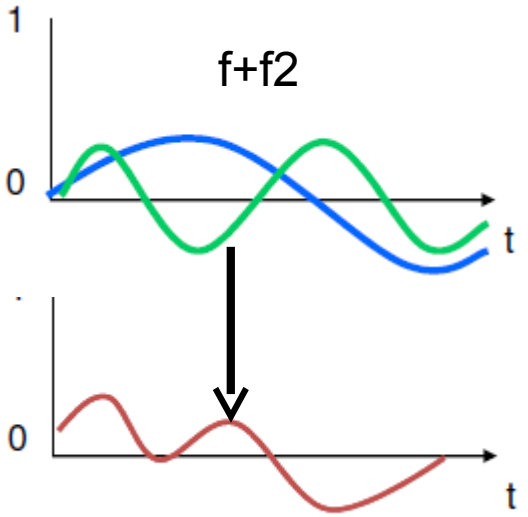
Audio beacon is a combination of one or more high frequency(>=18kHz) sinusoidal audio signal.



Audio Beacon tone with single frequency.



Audio Beacon tone with f2 frequency signal added.



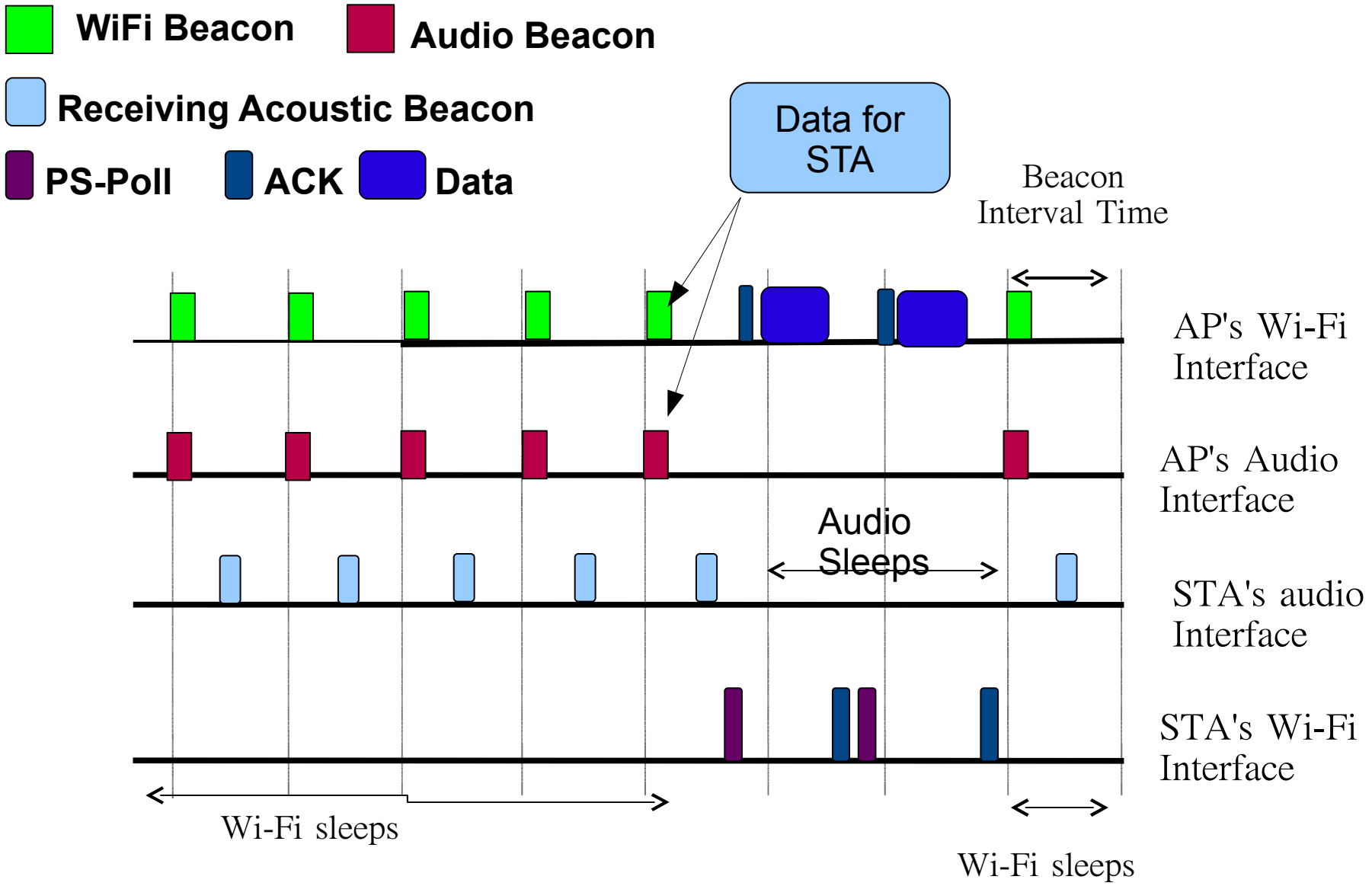
A2PSM: Design

In this project, we limit our scope to unicast transmission in Wi-Fi infrastructure mode.

The constraint in designing the A2PSM:

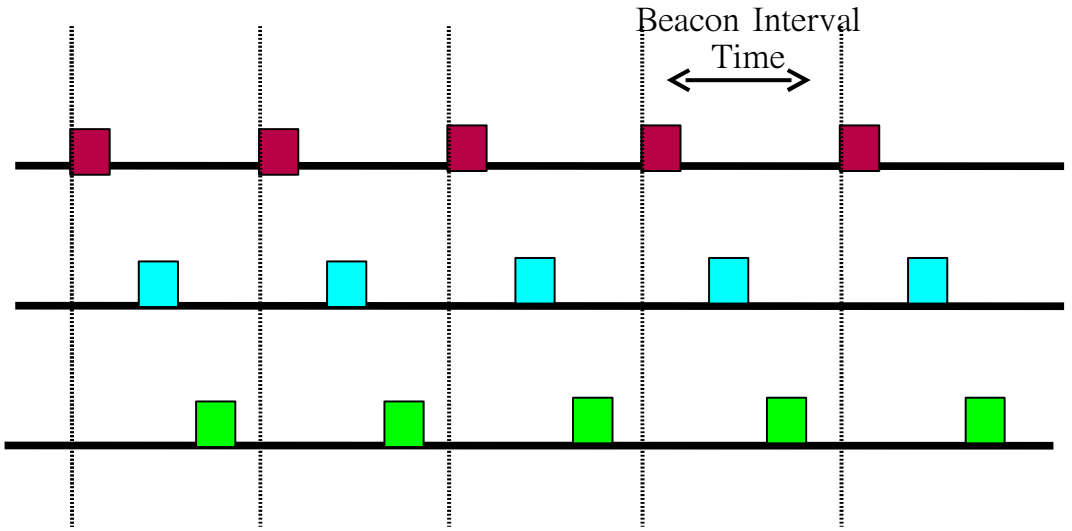
- The proposed PSM should cost less energy than the traditional Wi-Fi PSM.
- The audio interface needs to generate and receive the audio beacon within the Wi-Fi beacon period.
- A2PSM should support PSM for legacy devices.

A2PSM: Scheme



Relative Position/Range

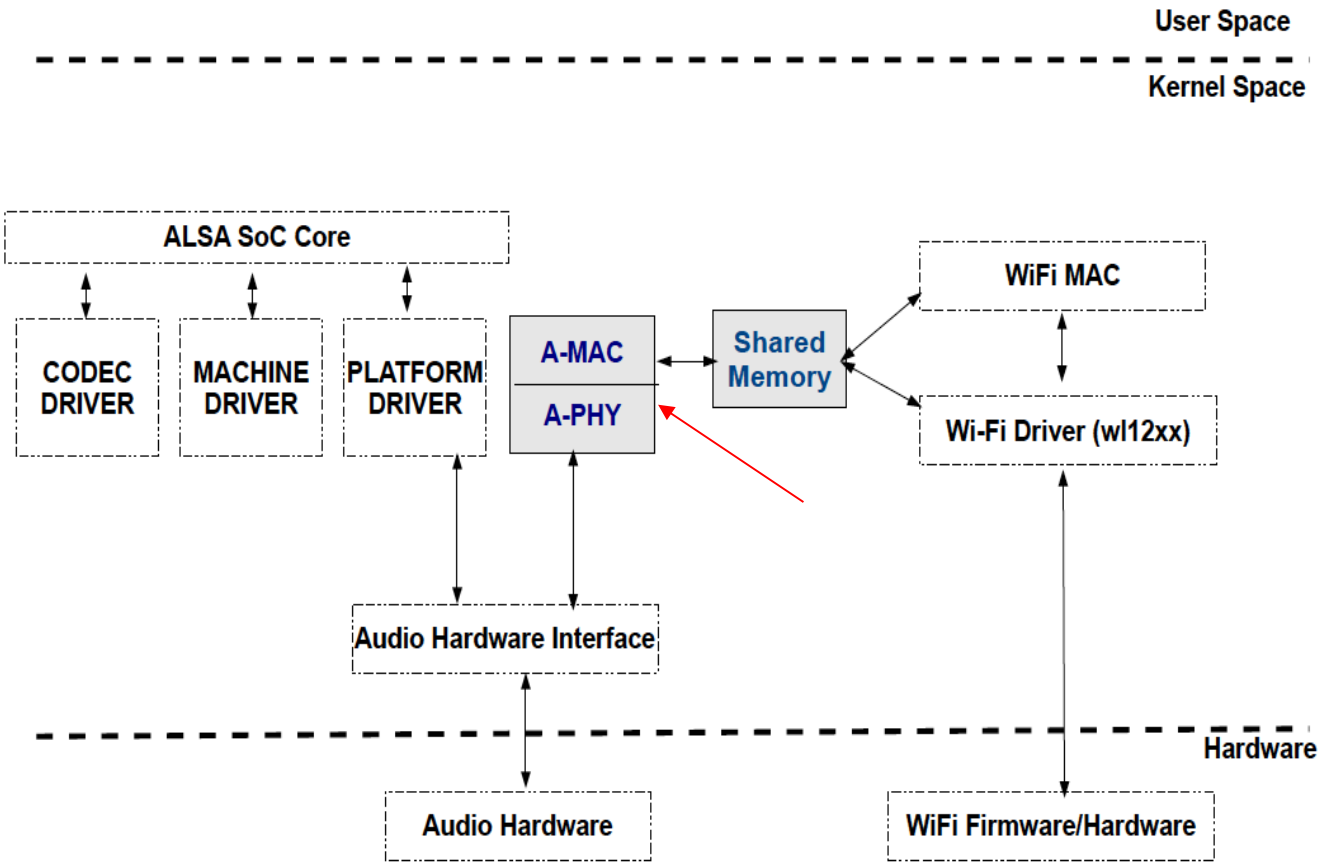
Propagation speed of the sound in air is relatively very slow compare to the electromagnetic wave.



STA1 is nearer to AP compare to STA2

- STAs at different distance from the AP receive the audio beacon at different time.
- The STA needs to estimate the relative distance from the AP (Using **relative ranging scheme**) to awake the audio interface just before receiving the audio beacon.

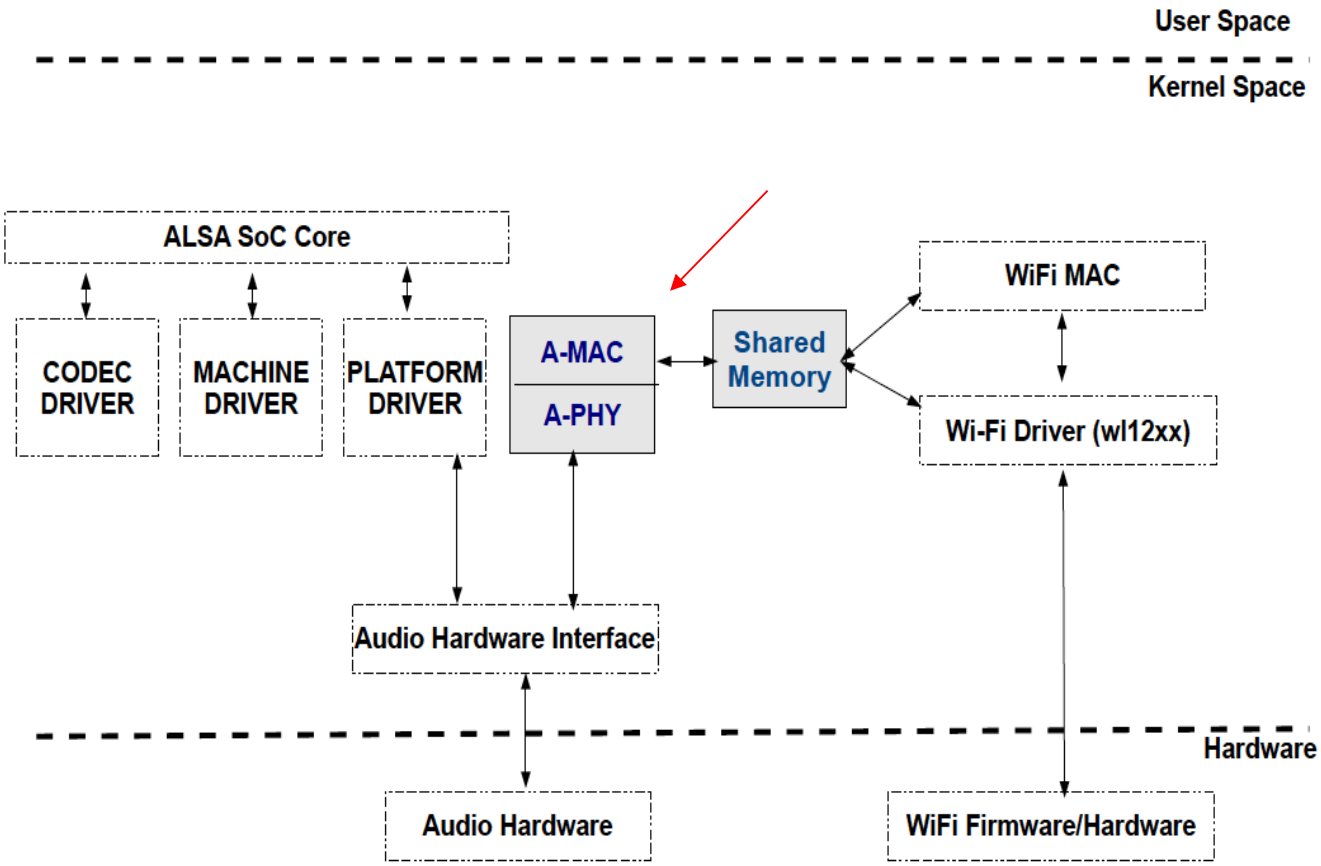
Implementation



A-PHY module in the AP only generates the audio beacon synchronized with the Wi-Fi Beacon

A-PHY module in the STA capture the audio

Implementation



A-MAC module in the AP communicate with the Wi-Fi MAC to define the frequency component in the audio beacon based on the STAs those have buffered data at AP.

A-MAC in the STA notifies the Wi-Fi MAC only when it detects the corresponding unique frequency component in the audio beacon tone.

Implementation

How long STA need to keep the audio interface awake to capture the audio beacon?

- Minimize the duration of keeping the audio interface awake at STA.
- We tune the parameters in sound driver to limit duration of transmitting the audio beacon signal to 10ms from the AP.
- The STA needs to keep the audio interface awake 10ms to detect the audio beacon, (which is identical to the period the Wi-Fi interface stays awake to receive a Wi-Fi beacon).

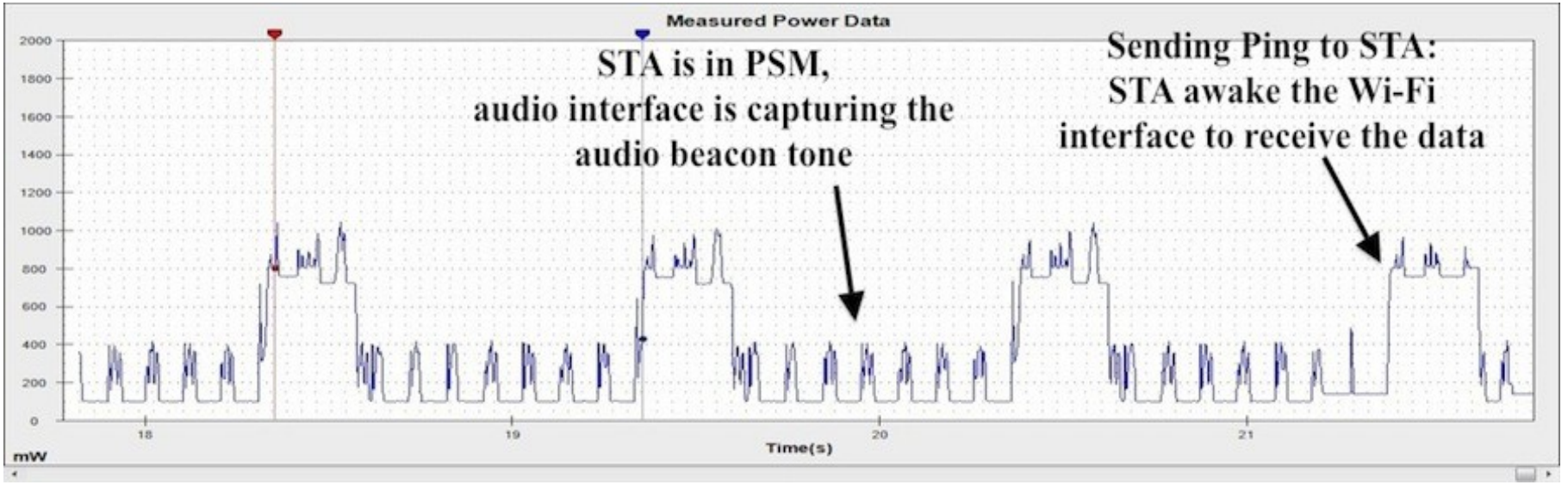
Implementation

How to minimize the miss-alignment between the transmission time of the audio beacon and the Wi-Fi beacon at the AP?

- Requires fast interaction between the audio and the Wi-Fi interface.
- We use a common shared memory and signals to interact between the Wi-Fi driver and the audio codec driver.

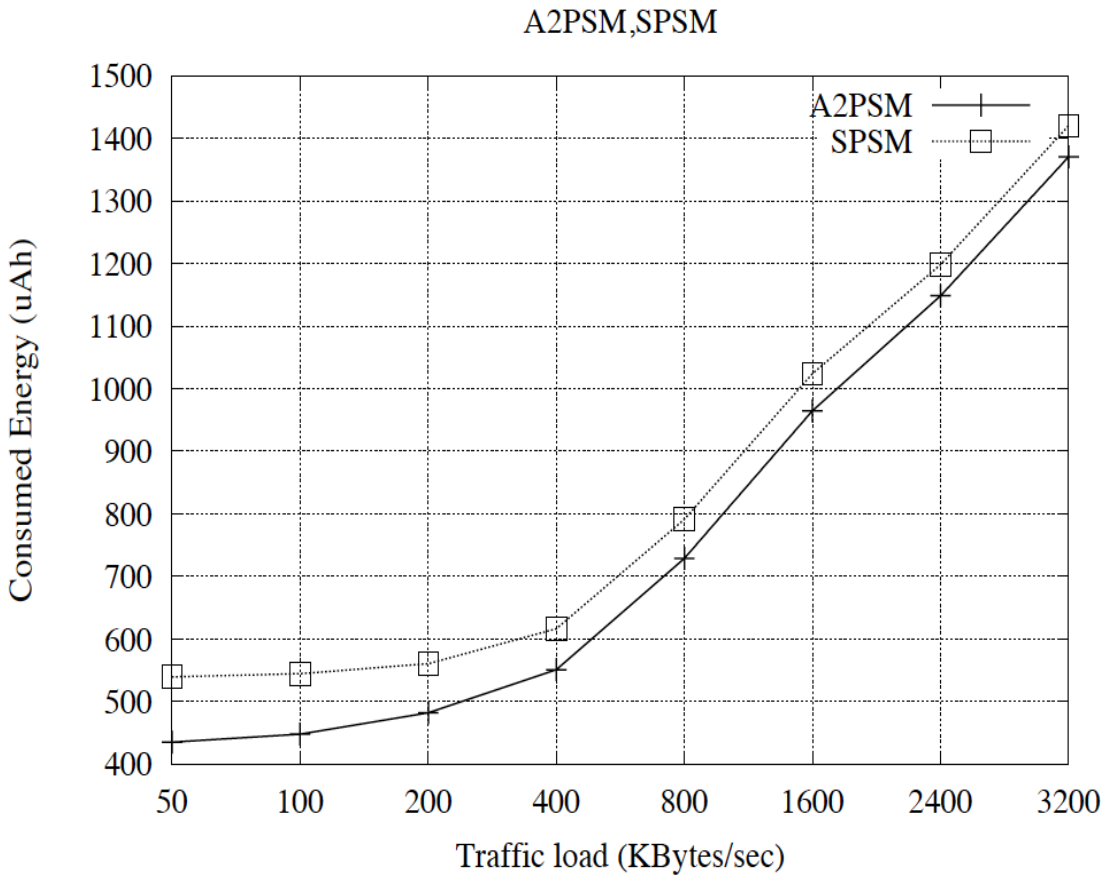
Experiment

- We Implemented the A2PSM prototype on two Nokia N900 smartphones. One as AP, other as STA
- We connect the STA with Monsoon Power Monitor to measure the energy consumption.
- We are sending periodic ping command through the AP to the STA.



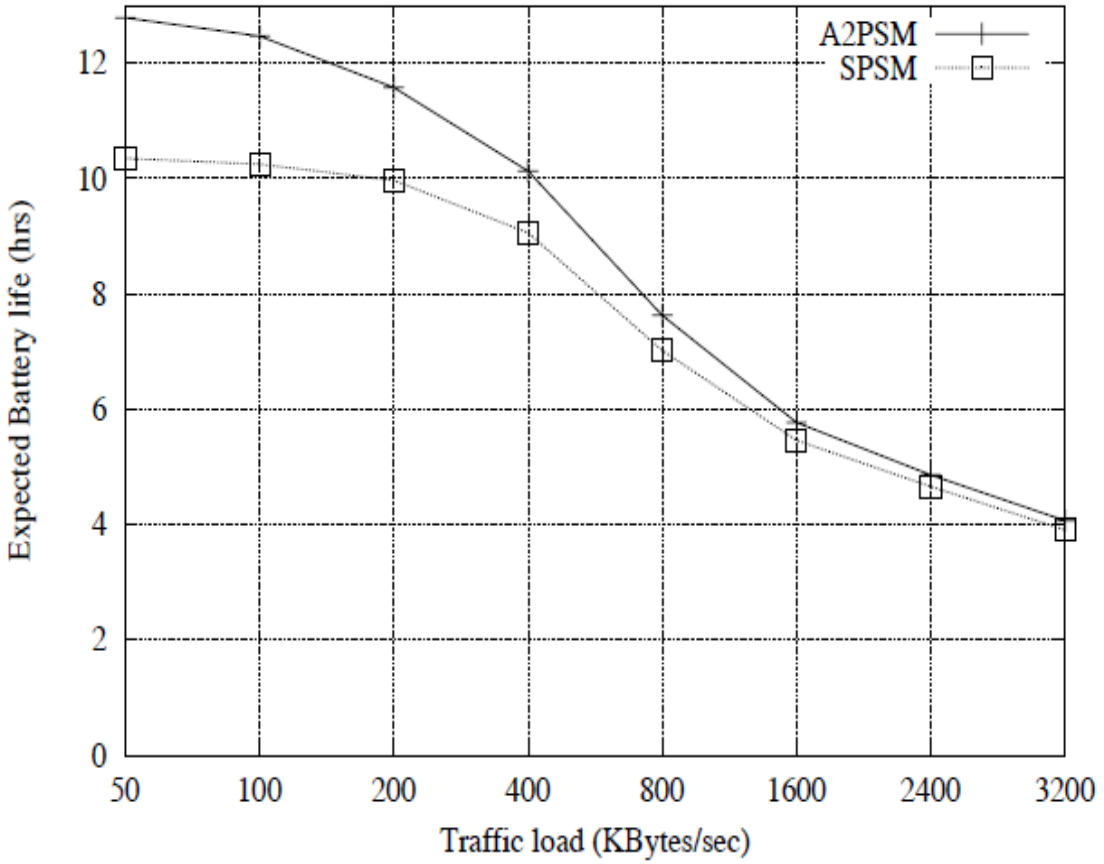
Above figure shows the proper operation of the A2PSM scheme

Evaluation



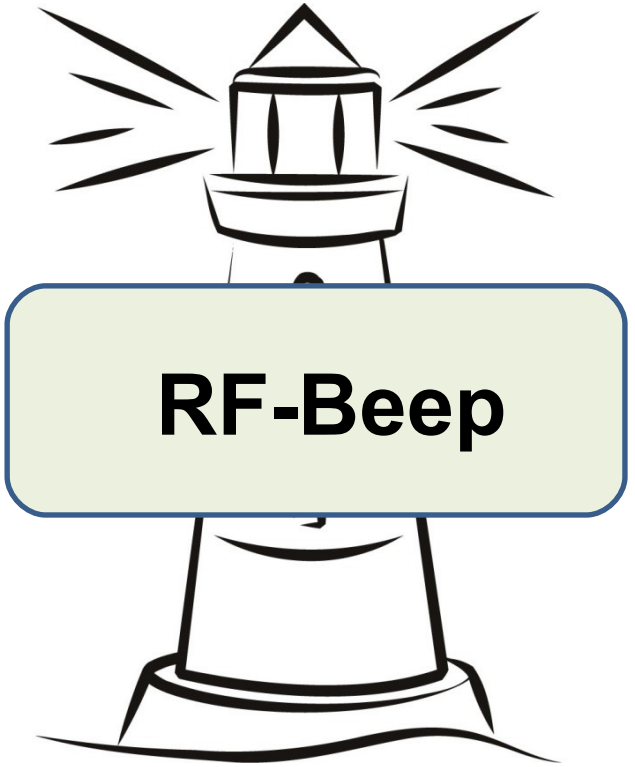
- We used iperf tool to control the traffic load between the STA and the AP.
- We replicate our experiment 10 times for different traffic load.
- During the experiment we fix the distance between the AP and the STA to 3 meter.
- We compare the power consumption between SPSM and A2PSM.
- A2PSM can save up to 25% more power than the SPSM.

Evaluation



Expected battery life time for both power saving scheme under different traffic load.

What is ranging scheme?



Estimate the distance from an anchor point

Applications

Customer:
right product

Seller:
Right customer

ADVERTISING

Applications

MARKETING

Applications

HEALTHCARE

Applications

- Accurate localization
- Face-to-face gamming applications.
- Driver phone detection

And many more….

RF-Beep Ranging

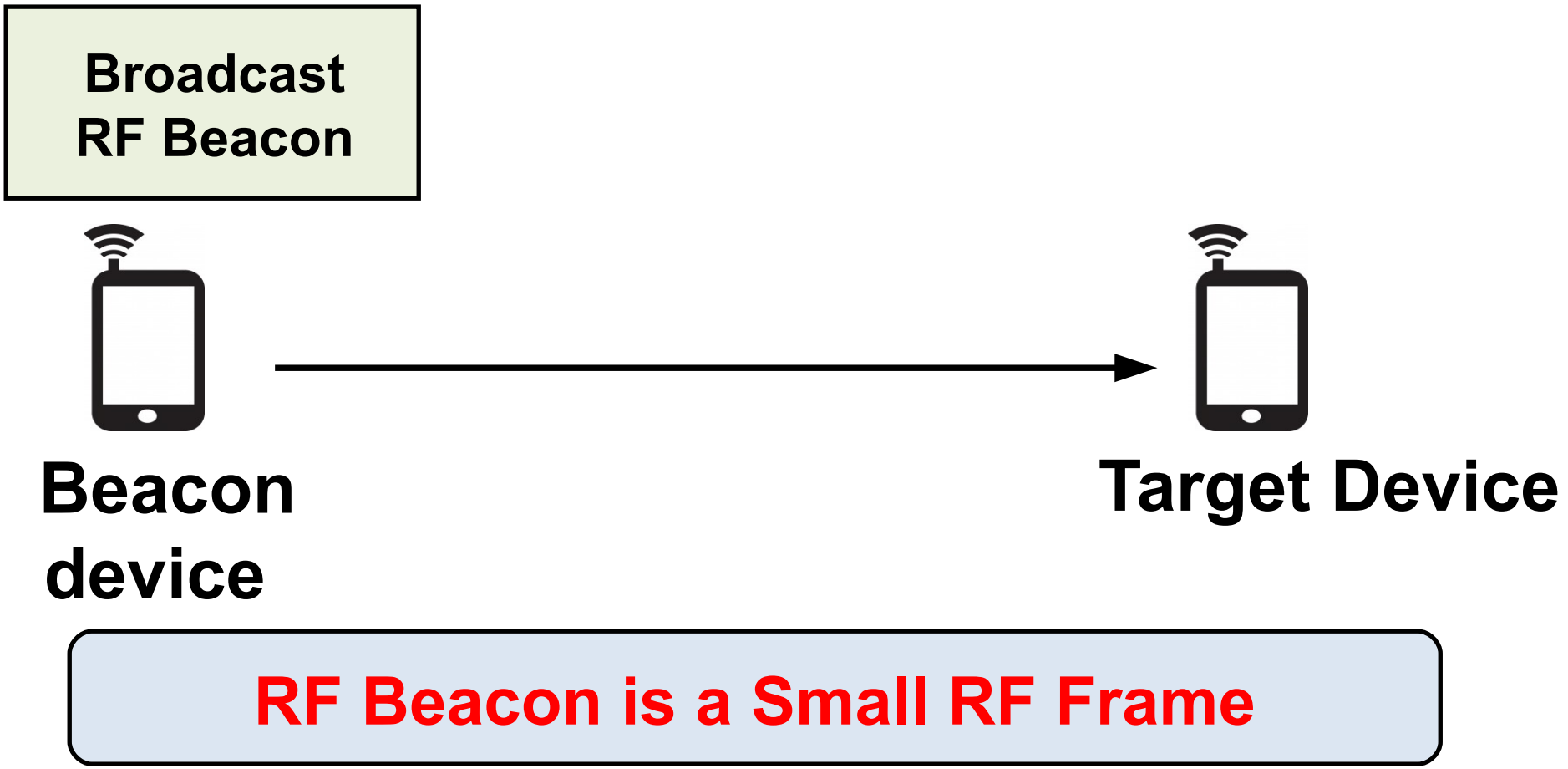
Beacon device

Target Devices

Smart device that have RF and audio interface

Target device estimate relative distance to beacon device .

How RF-Beep works?

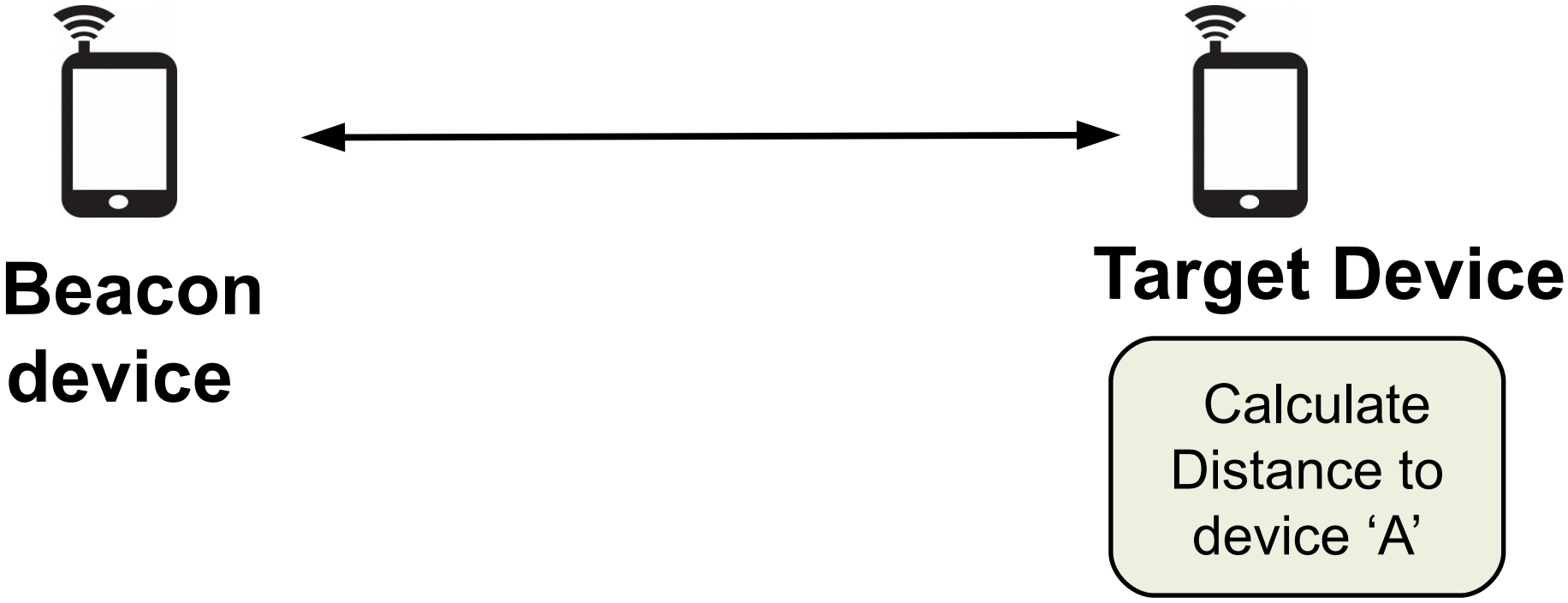


How RF-Beep works?

Beep sound is a high frequency sinusoidal acoustic signal with a single frequency.

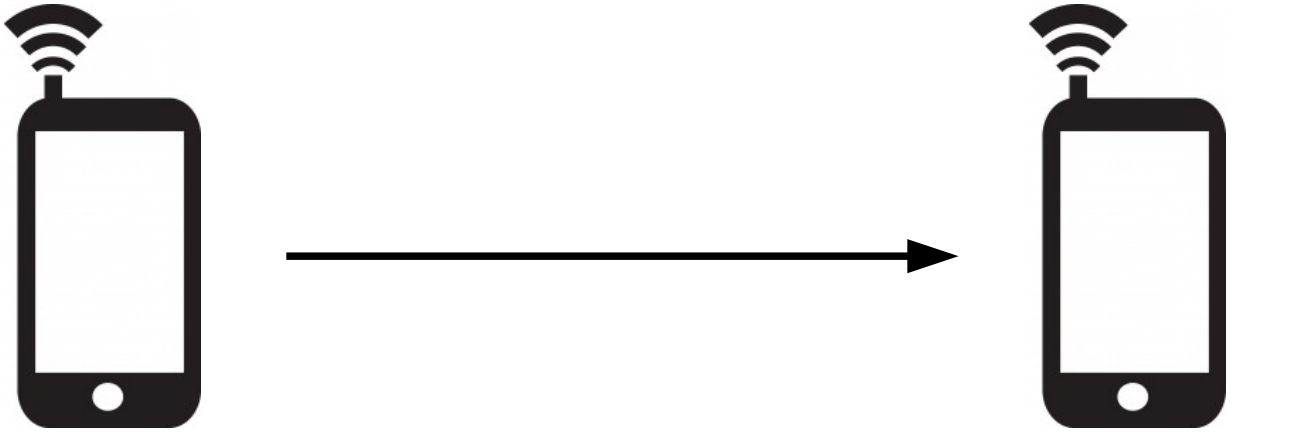
How RF-Beep works?

TDoA technique that utilizes the relative speed between RF and Acoustic signal.

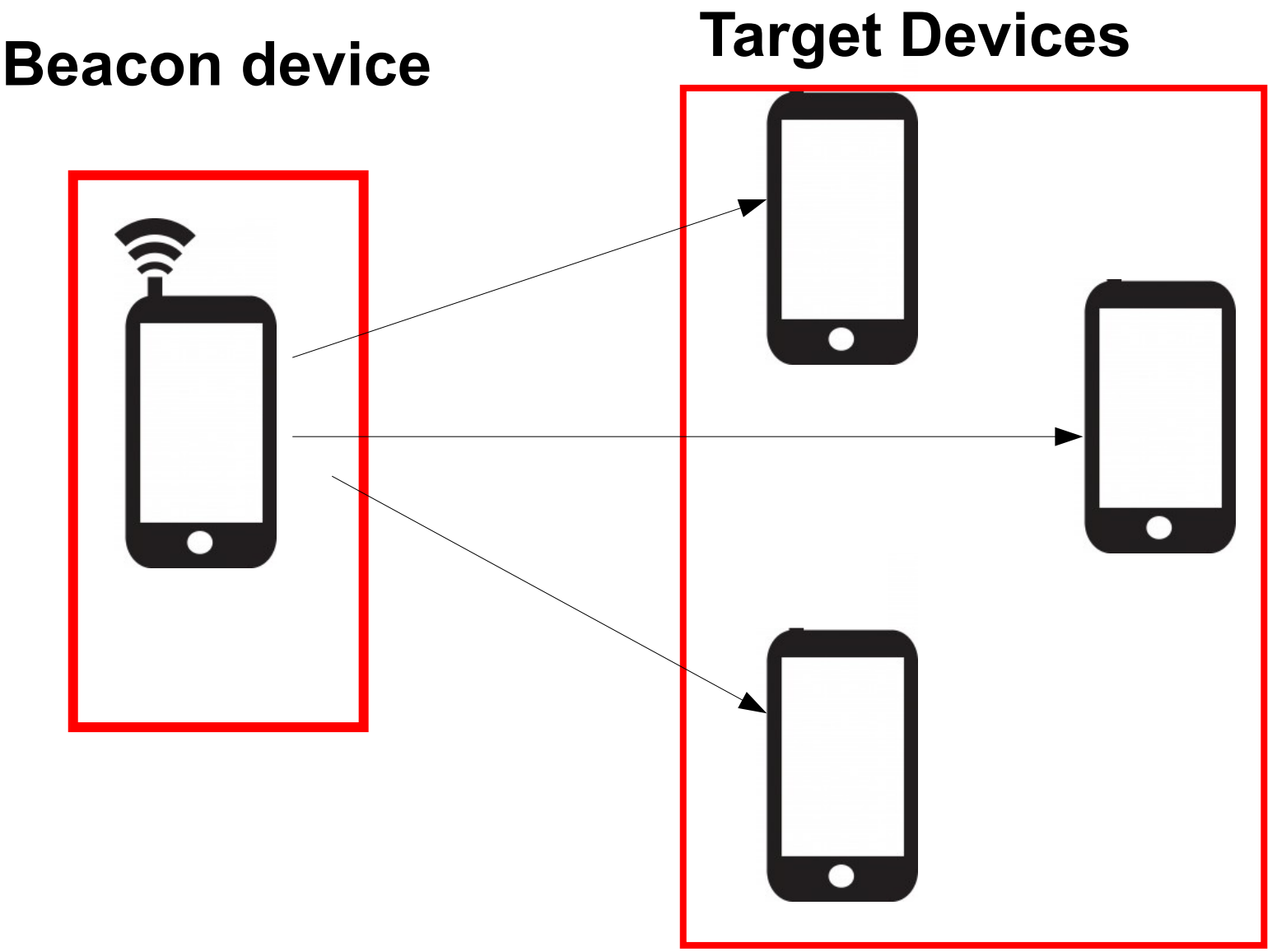


Features in RF-Beep

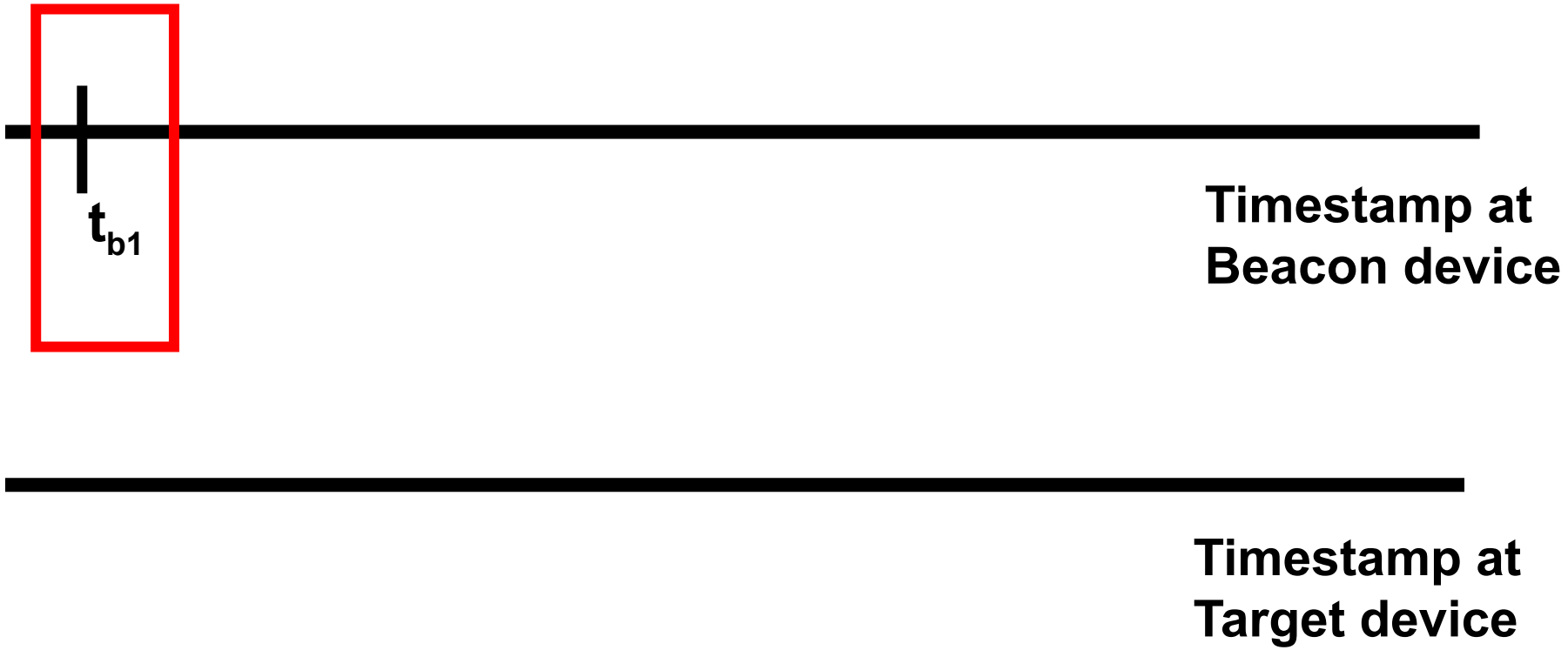
- COTS Smart Device Usability
- One-way sensing
- Energy Efficient
- Distributed
- Preserve Privacy



One-to-many scenario

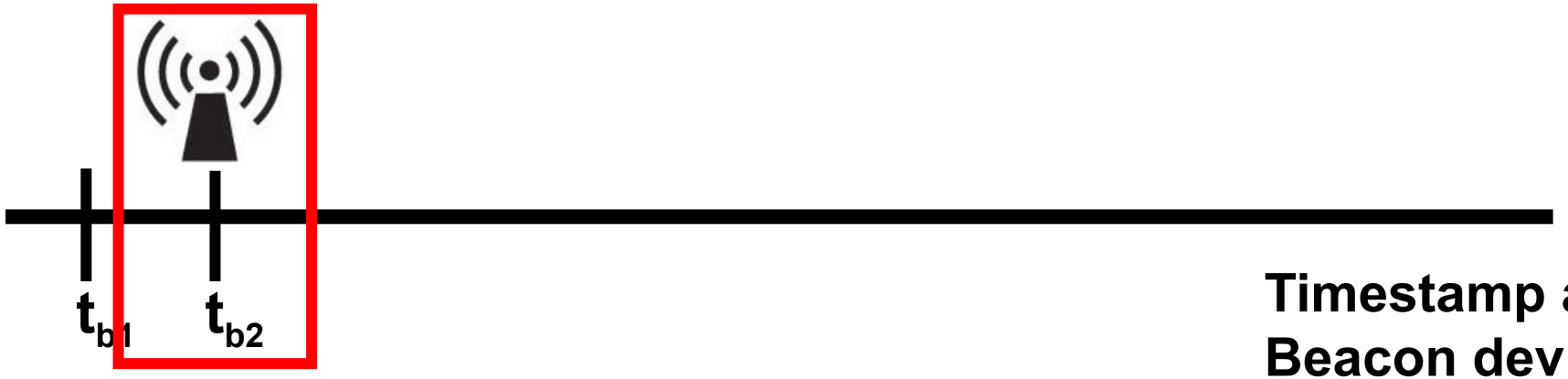


RF-Beep: Time events



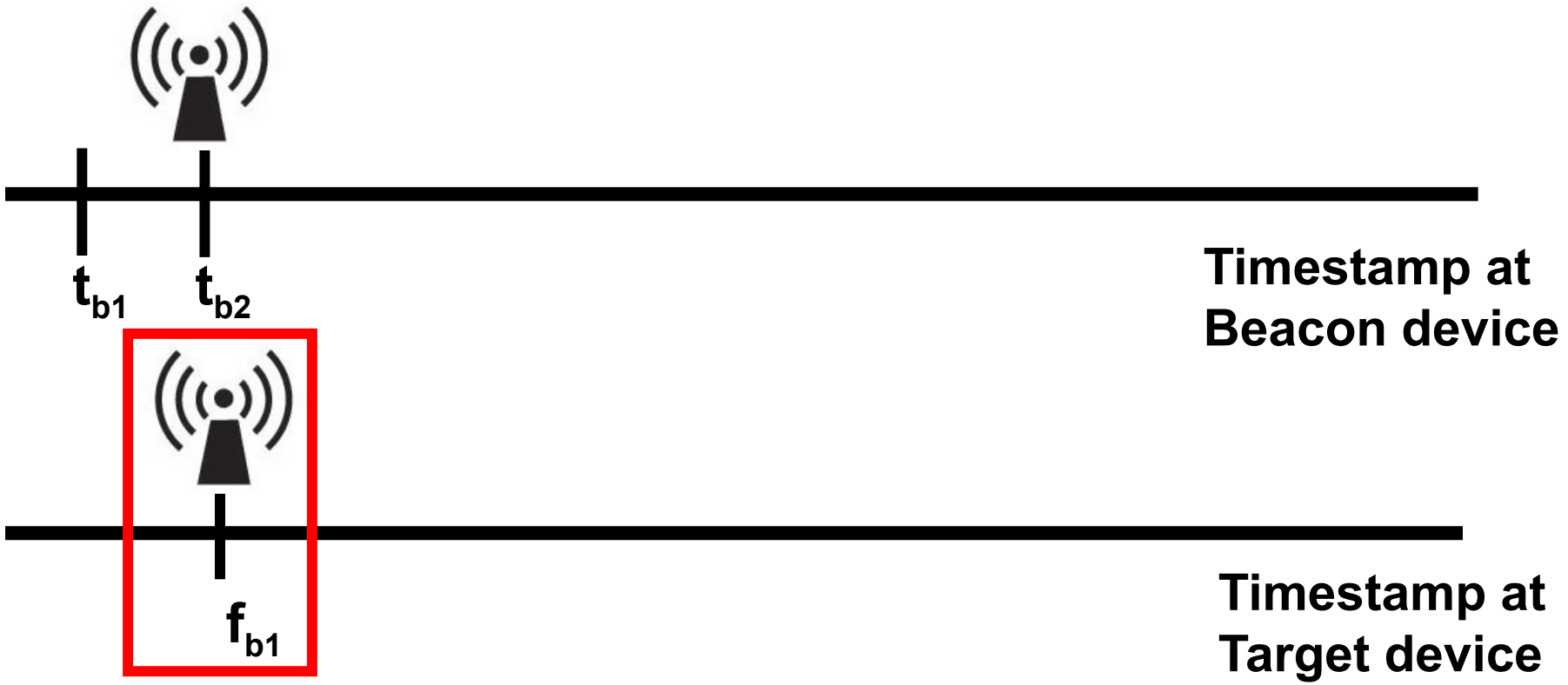
Time when beacon device puts the RF beacon into the transmission buffer to transmit

RF-Beep: Time events



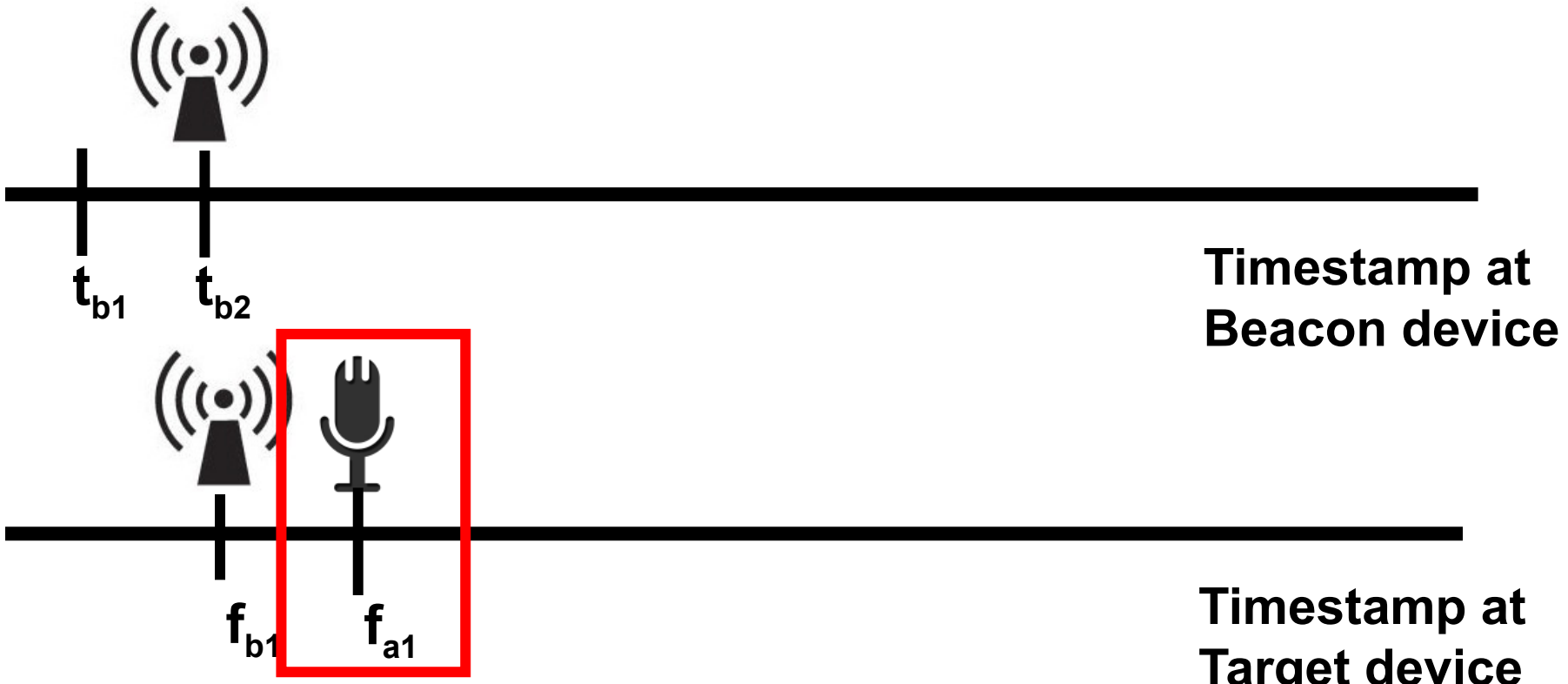
Time when beacon device's RF hardware interrupts for successfully transmitting RF beacon

RF-Beep: Time events



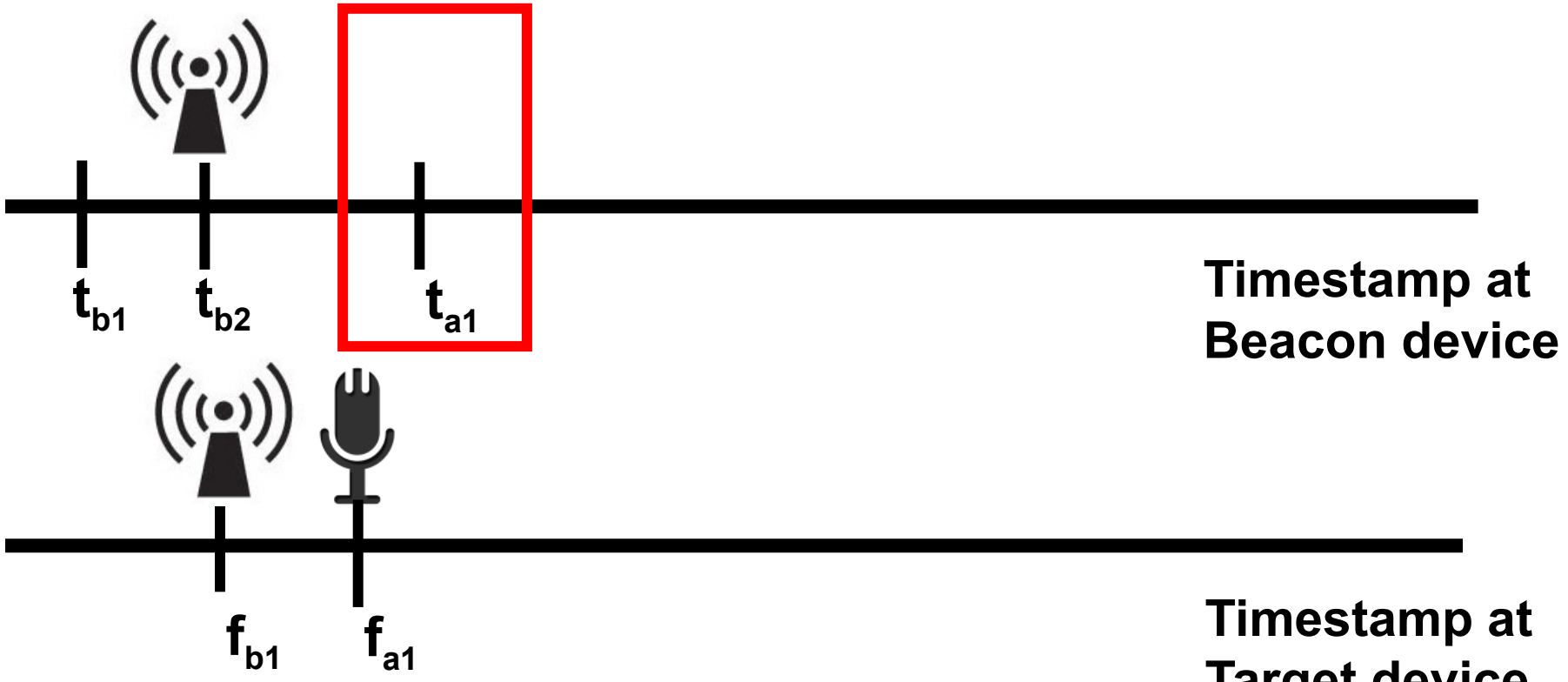
Time when target device's RF hardware interrupts for successfully receiving the RF beacon

RF-Beep: Time events



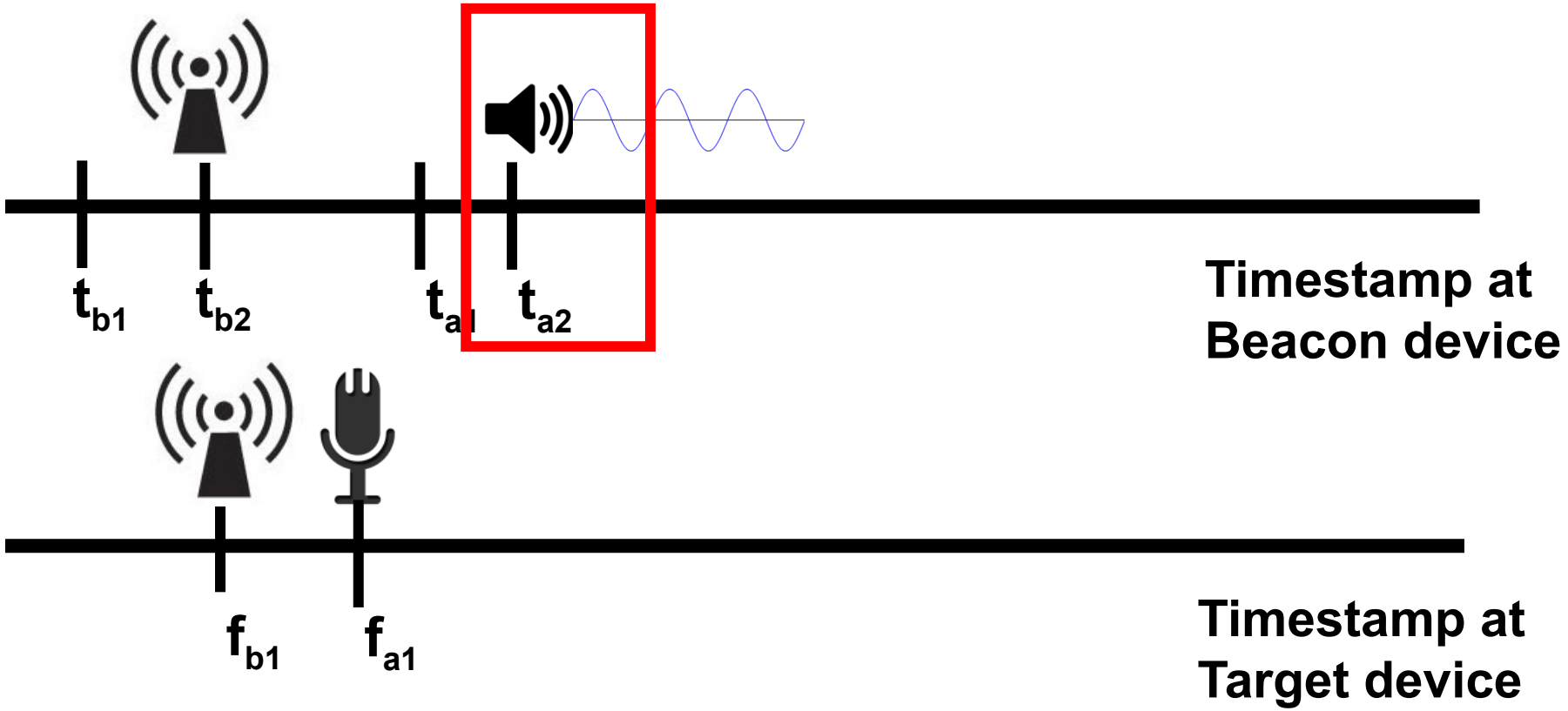
Time when the target device's microphone starts capturing the audio samples.

RF-Beep: Time events



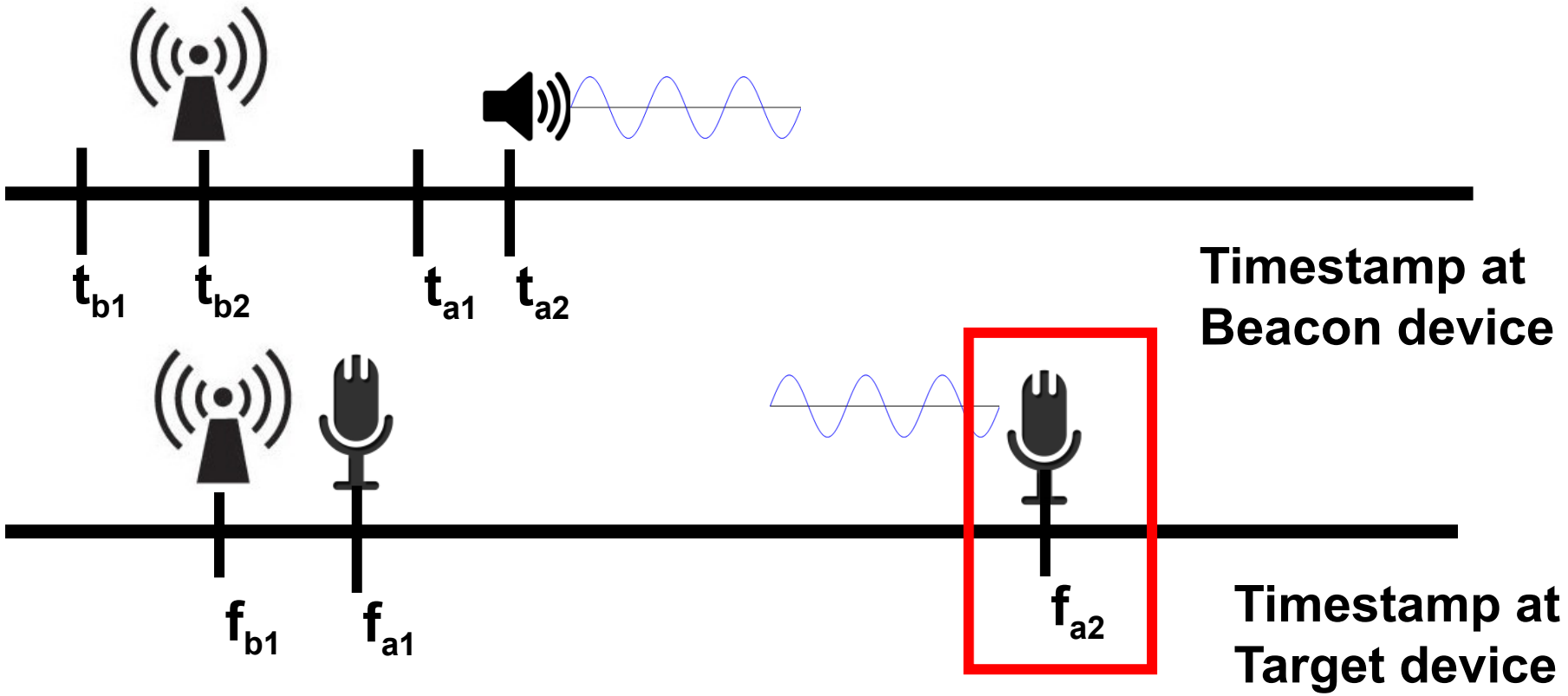
Time when beacon device's starts writing beep sound into the audio hardware.

RF-Beep: Time events



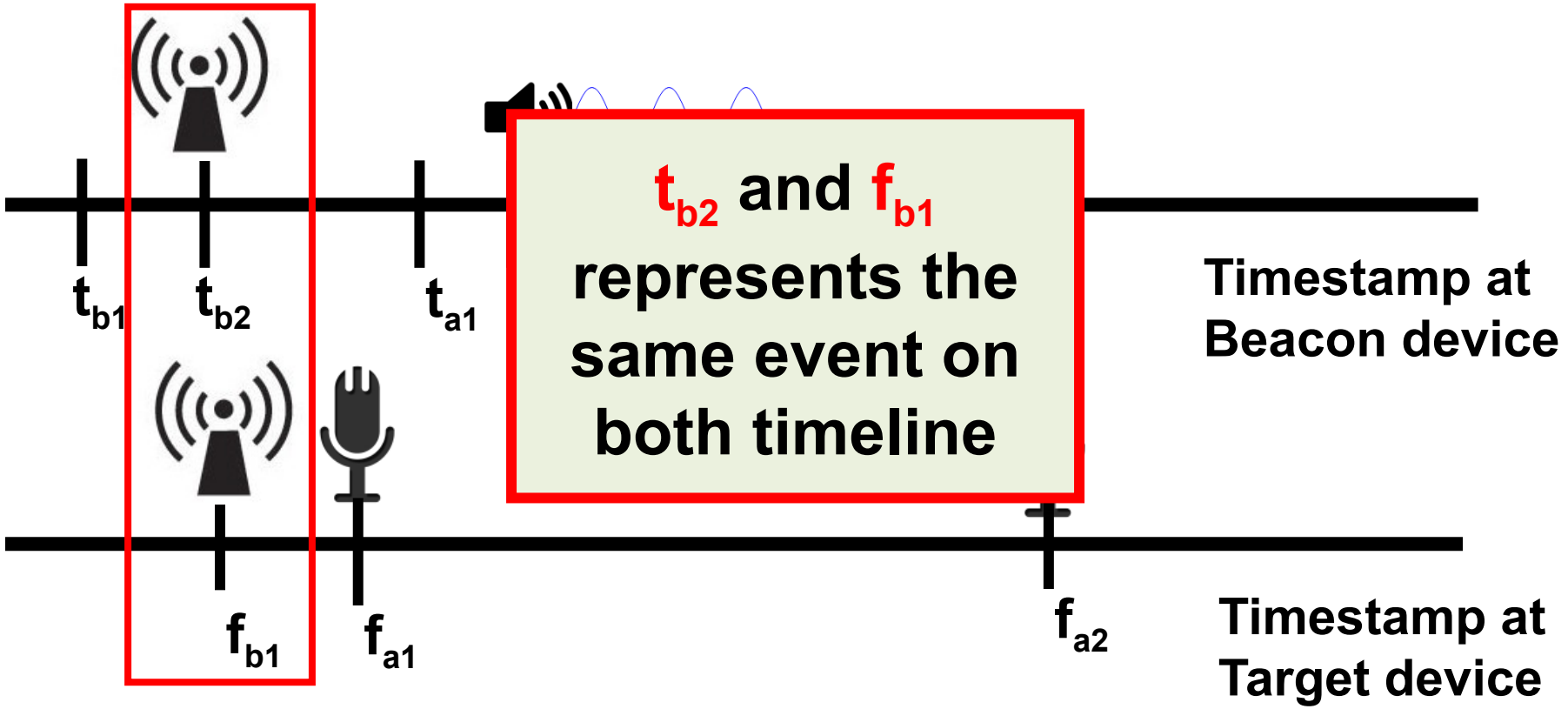
Time when the beacon device's speaker starts to generate the Beep sound.

RF-Beep: Time events



Time when the target device starts receiving the beep sound from the beacon device.

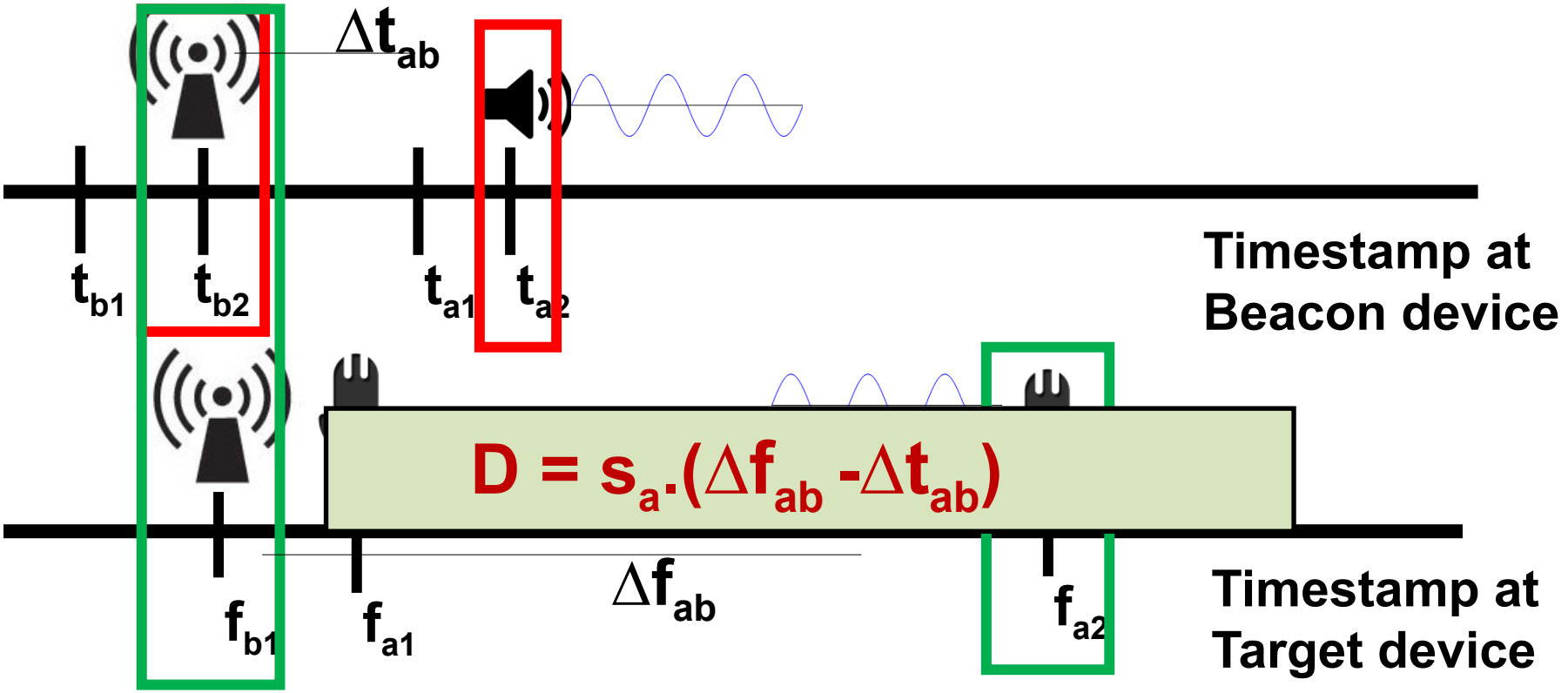
RF-Beep: Time events



High propagation speed of the RF signal

Small length of the RF beacon

Distance Calculation

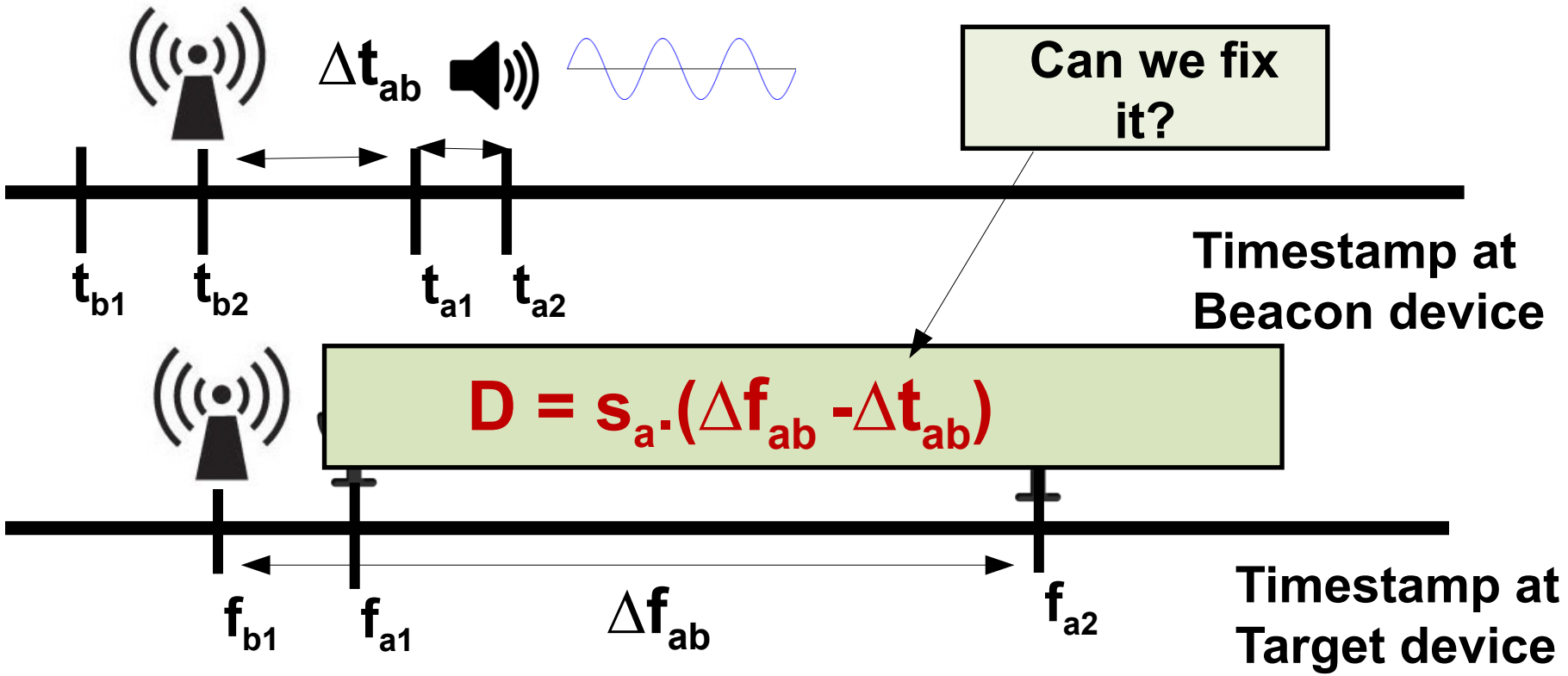


$$D = s_a.(f_{a2} - t_{a2})$$

$$D = s_a.(f_{a2} - t_{a2} + t_{b2} - t_{b2})$$

$$D = s_a.((f_{a2} - f_{b1}) - (t_{a2} - t_{b2}))$$

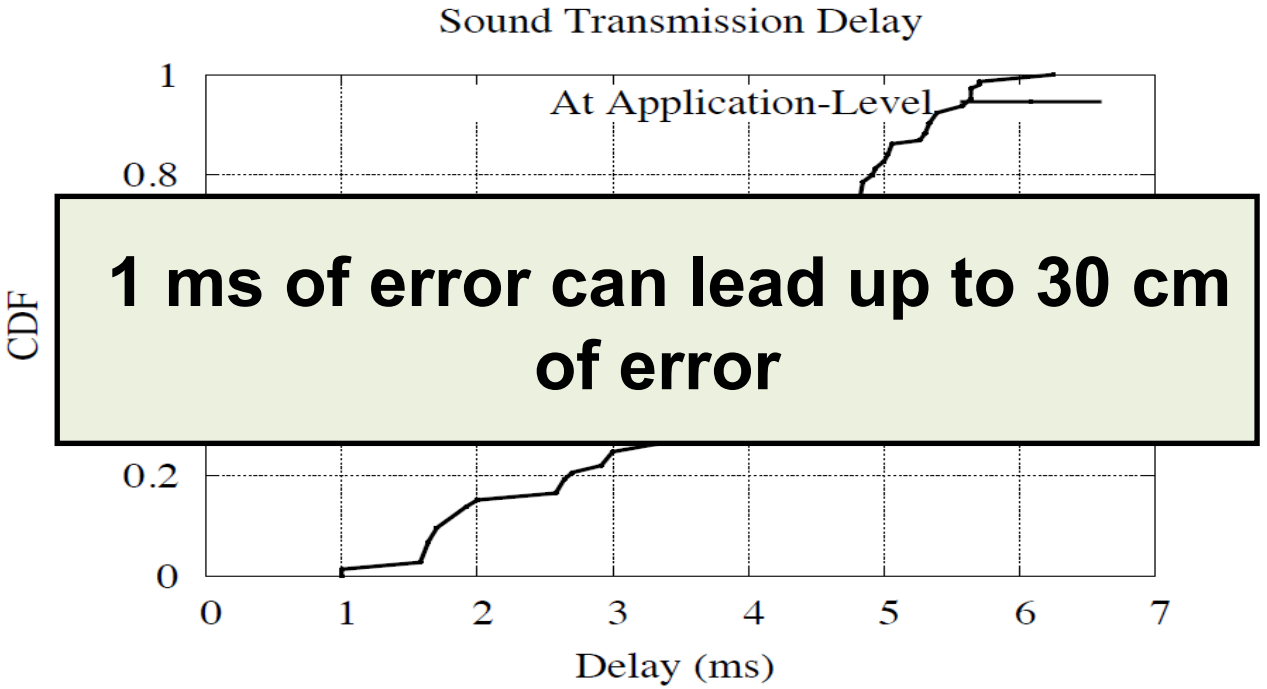
Distance Calculation



Δf_{ab} is known to the target device

Δt_{ab} contains the time variability (red section) of emitting acoustic signal from speaker

Challenge in Playing Beep



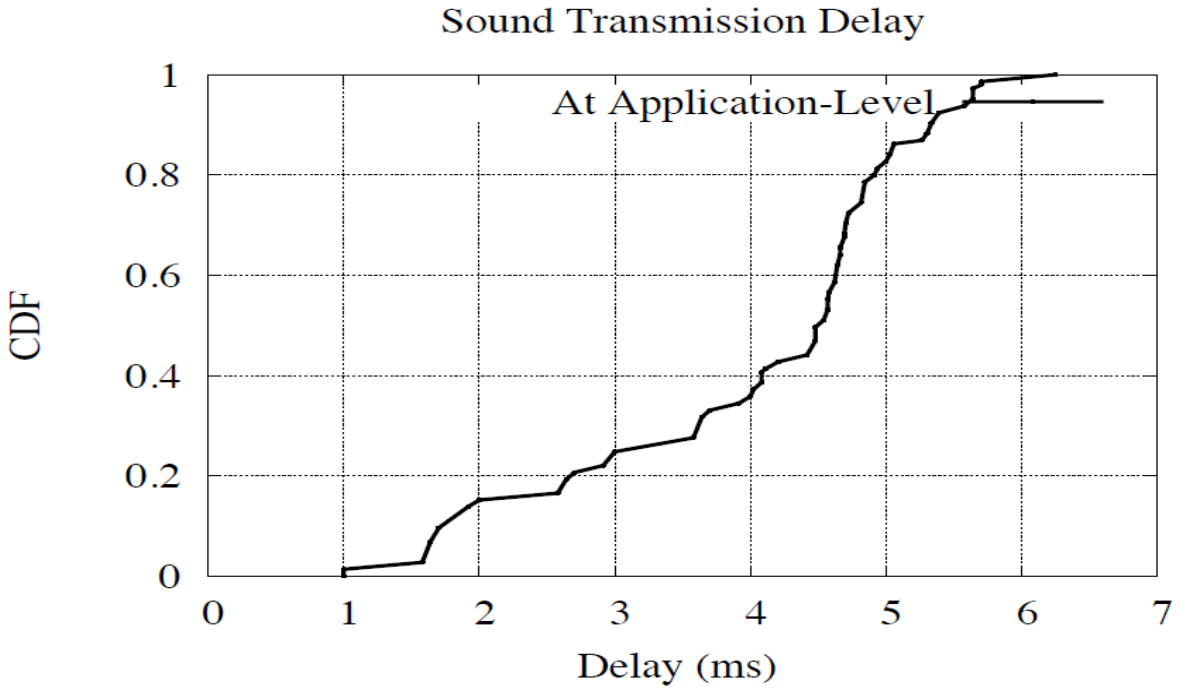
1 ms of error can lead up to 30 cm of error

Transmit of acoustic Signal from Application space

Highly variable

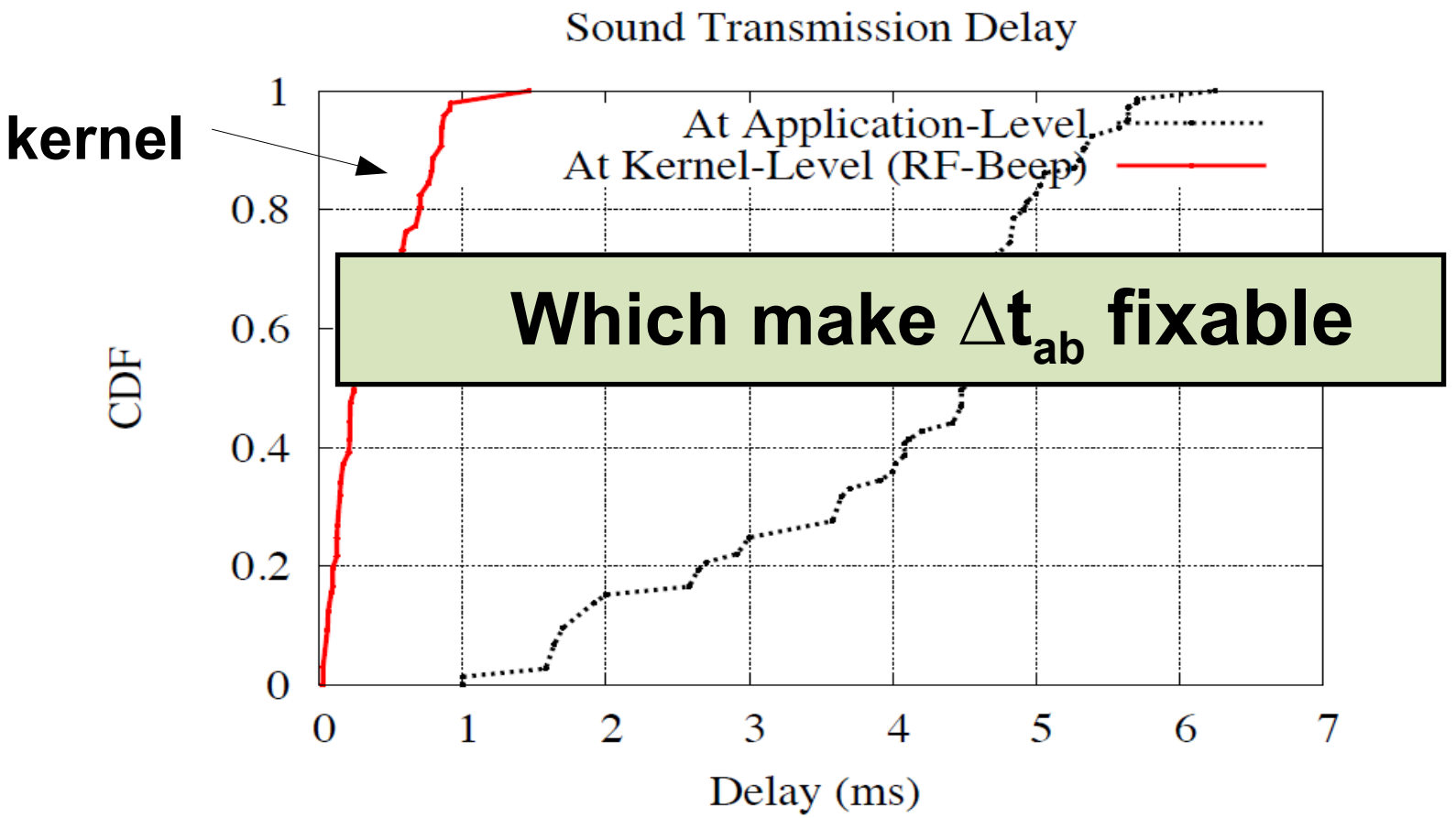
Emission of acoustic signal from the speaker

Challenge in Playing Beep



- ❑Power up the playback stream ✔
- ❑~~Data transfer between application to sound driver~~
- ❑DMA data transfer between sound driver to sound hardware

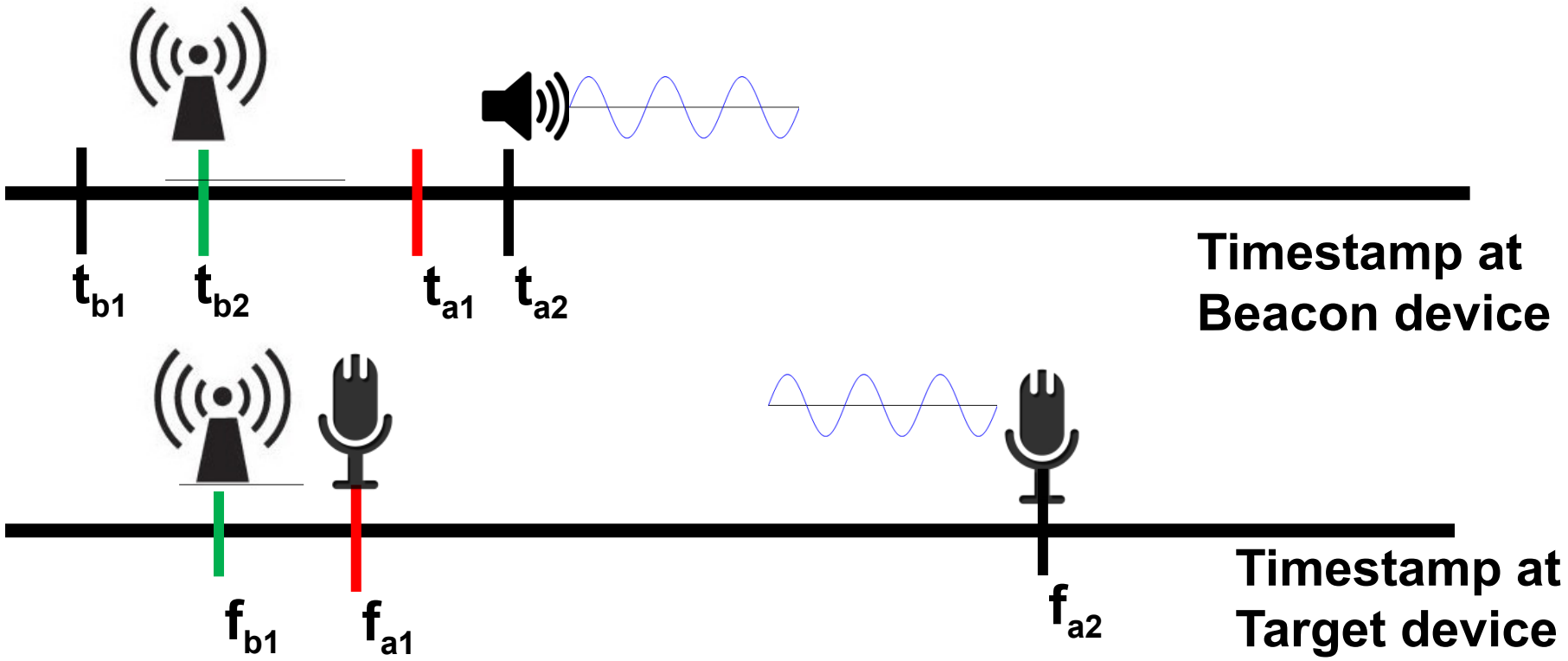
Challenge in Playing Beep



Which make Δt_{ab} fixable

- **Delay comparison between transmitting beep sound from application space and kernel space**

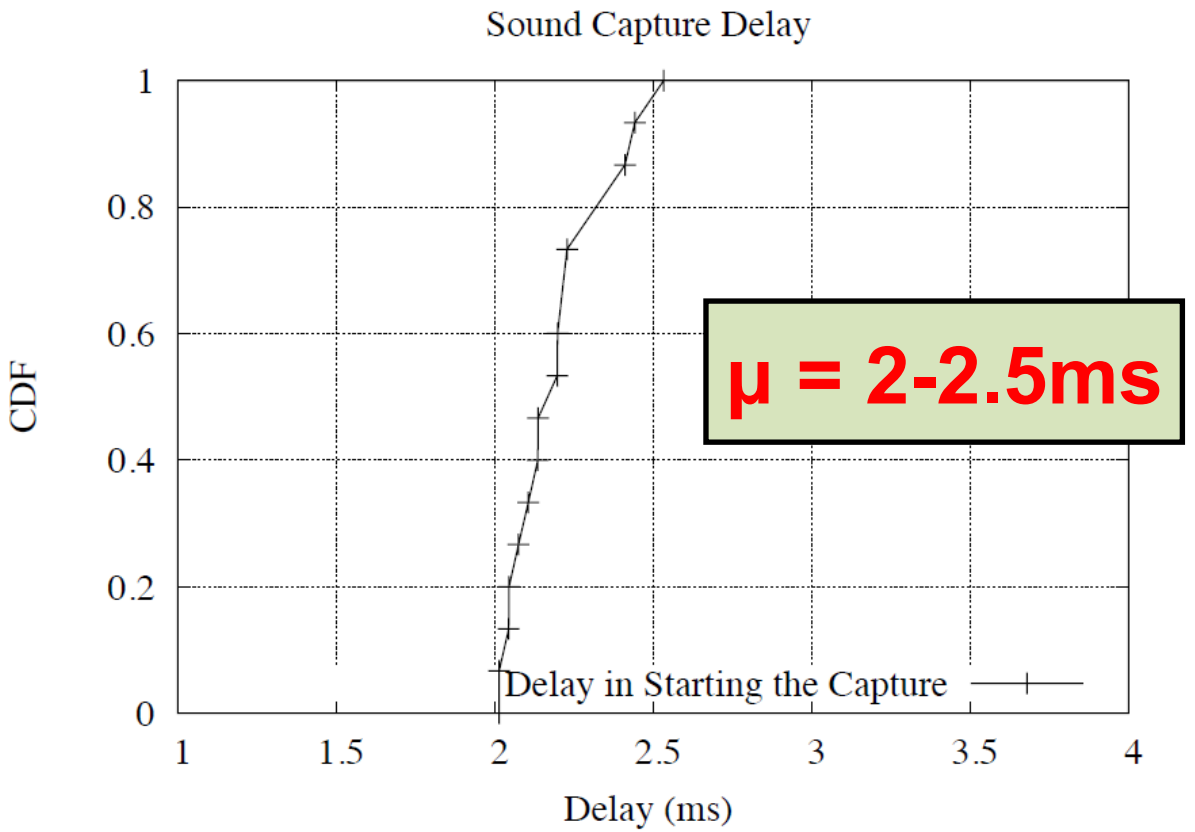
Challenge in Capturing Beep



$$(t_{a1} - t_{b2}) - (f_{a1} - f_{b1}) > 0$$

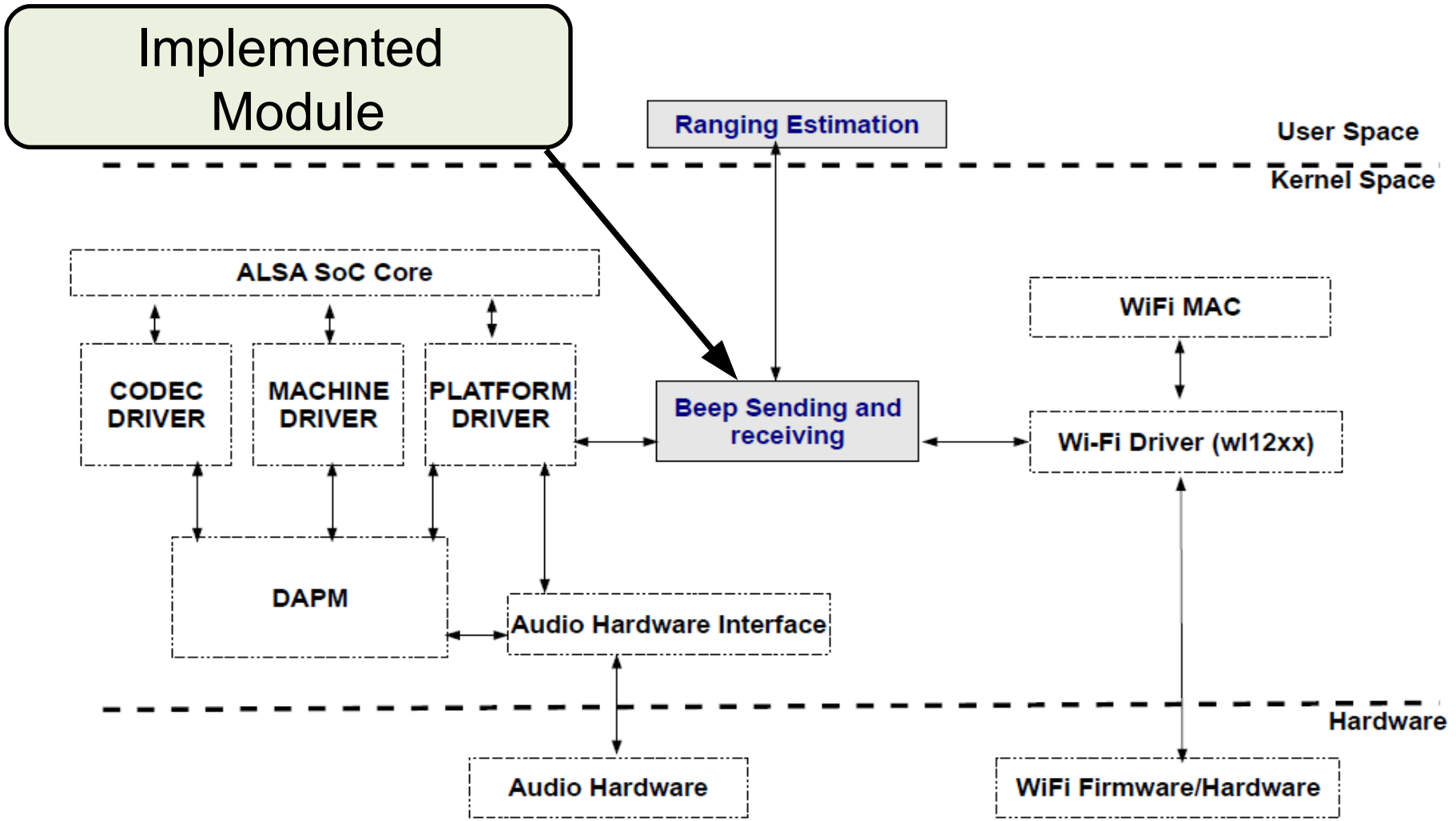
beacon device should not generate the Beep sound before the target device starts capturing

Challenge in Capturing Beep



- Power up the capture stream

RF-Beep Architecture



RF-Beep: Implementation

RF-Beep Architecture

Beep Signal Generation

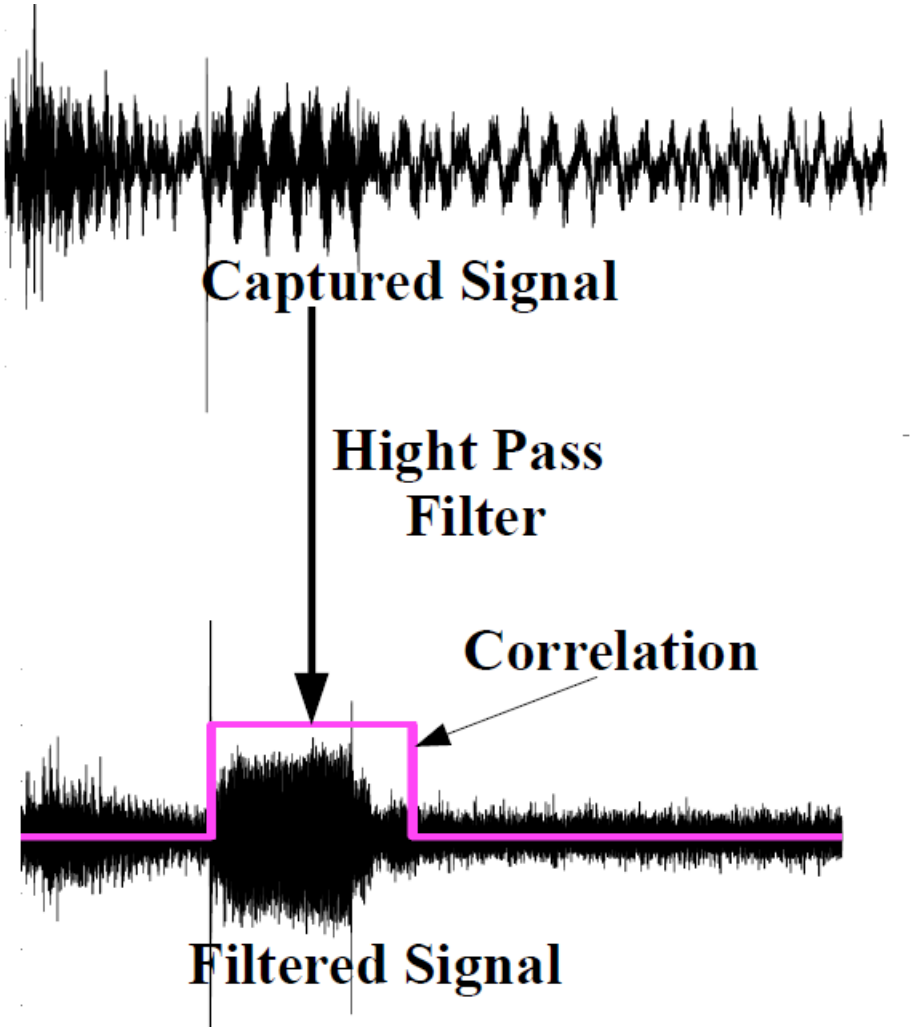
- **Frequency 18kHz**
- **Δt_{ab}= 5ms**

RF-Beep: Implementation

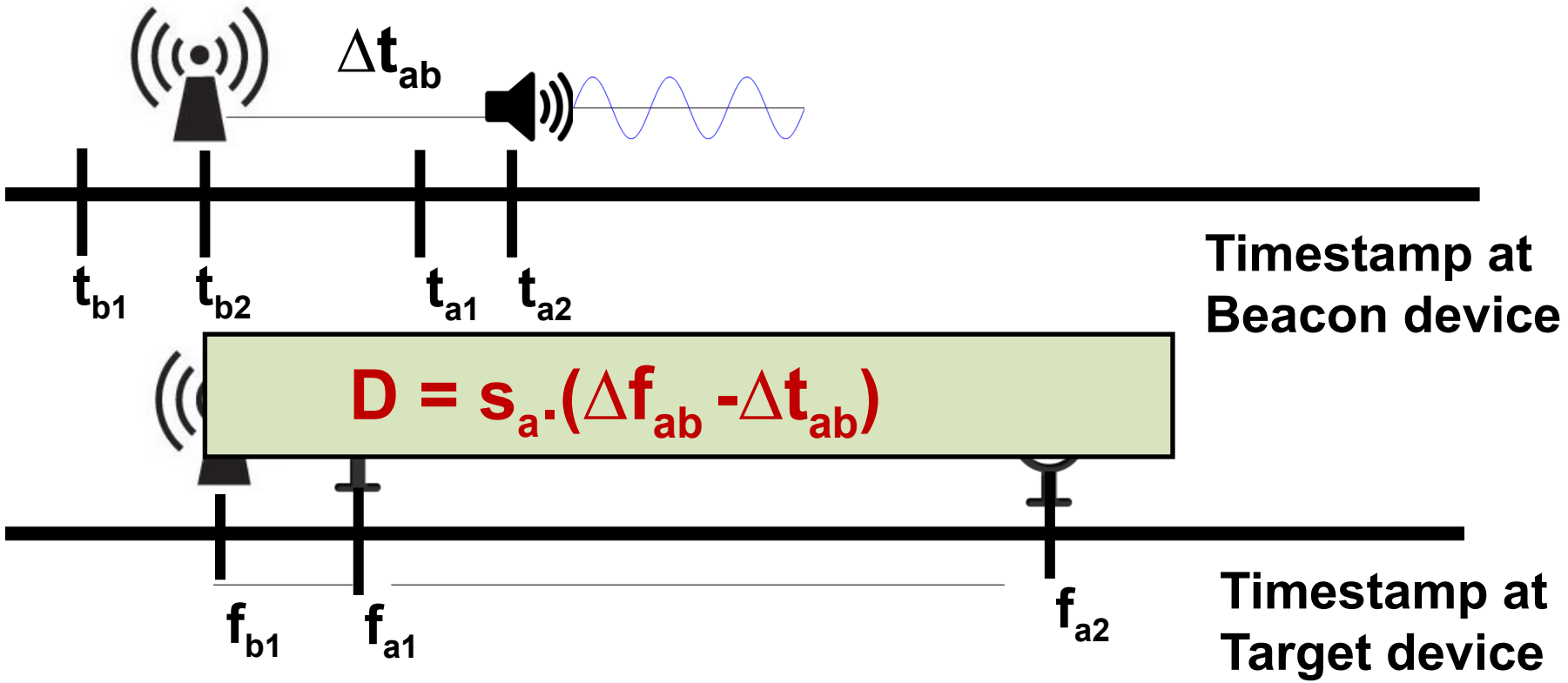
RF-Beep Architecture

Beep Signal Generation

Beep Signal Detection



RF-Beep: Range Estimation



$$\Delta f_{ab} = \mu + n_{ab}/f_s$$

n_{ab} , is the starting sampling # of the capture Beep sound f_s , sampling frequency.

Experiment Equipment

We Implement RF-Beep in Nokia N900

Audio Interface is supported by ALSA SoC driver

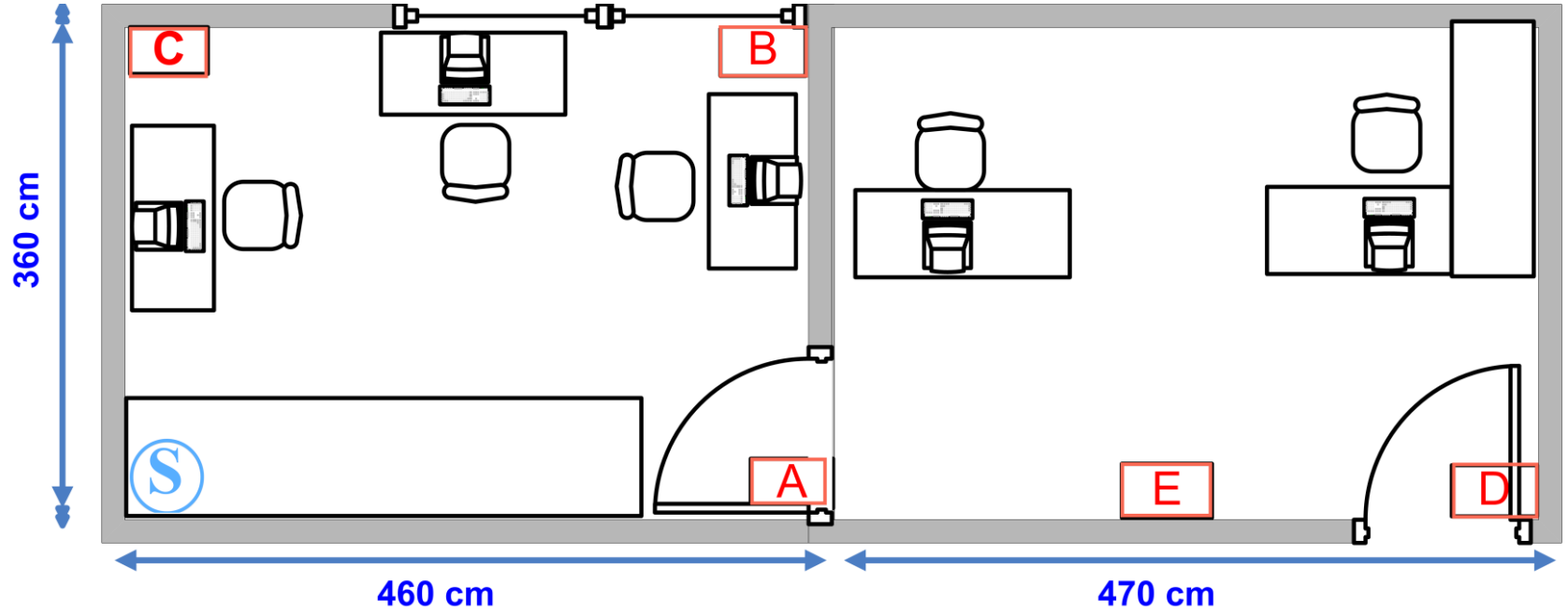
WiFi Interface is supported by wl12xx driver

Experiment Scenarios

Indoor-quiet

Indoor-noisy

Outdoor-open space



Experiment Scenarios

Indoor-quiet

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Experiment Scenarios

Indoor-quiet

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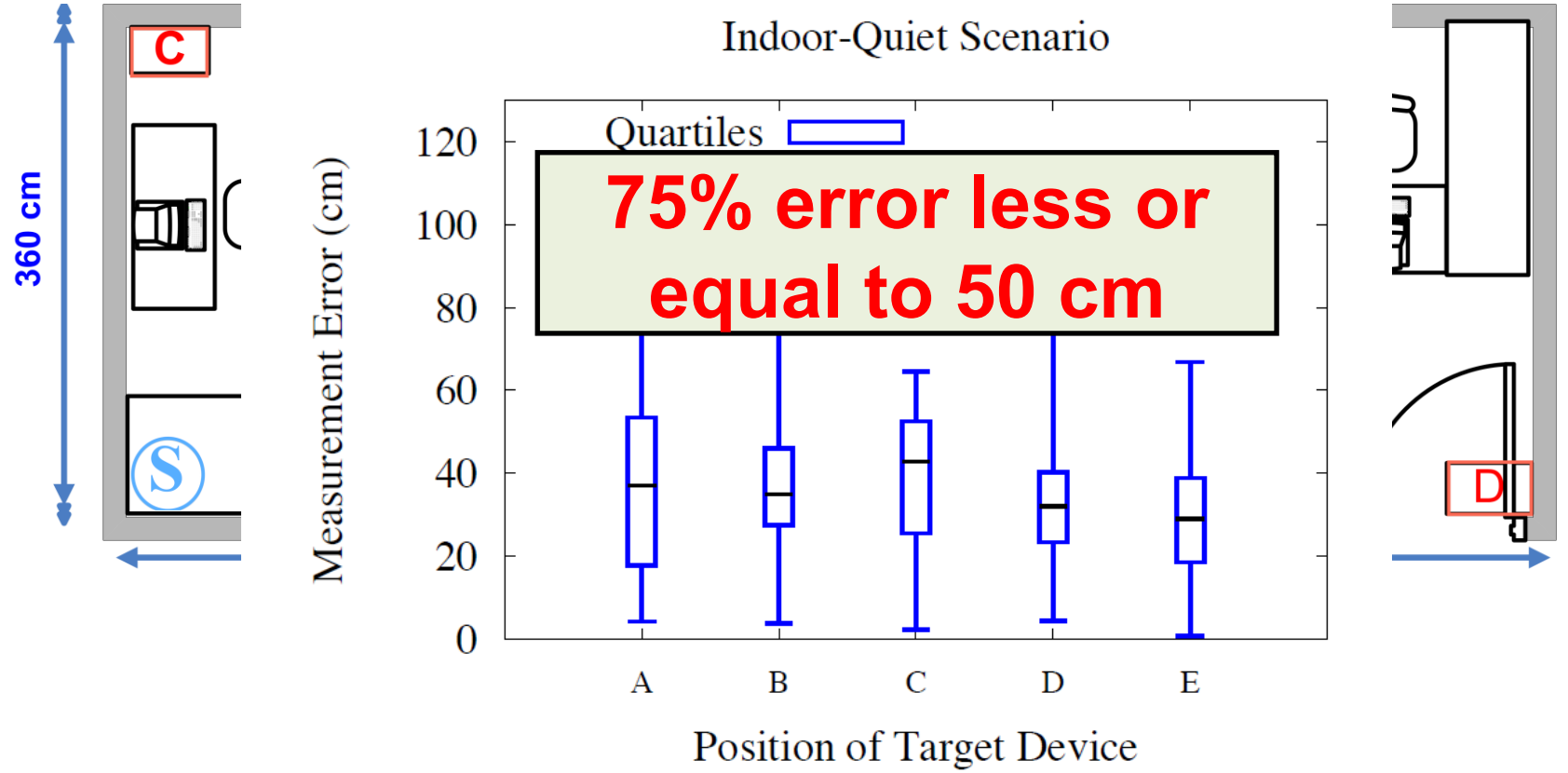
RF-Beep: Evaluation

Indoor-quiet

Indoor-noisy

Outdoor-open space



RF-Beep: Evaluation

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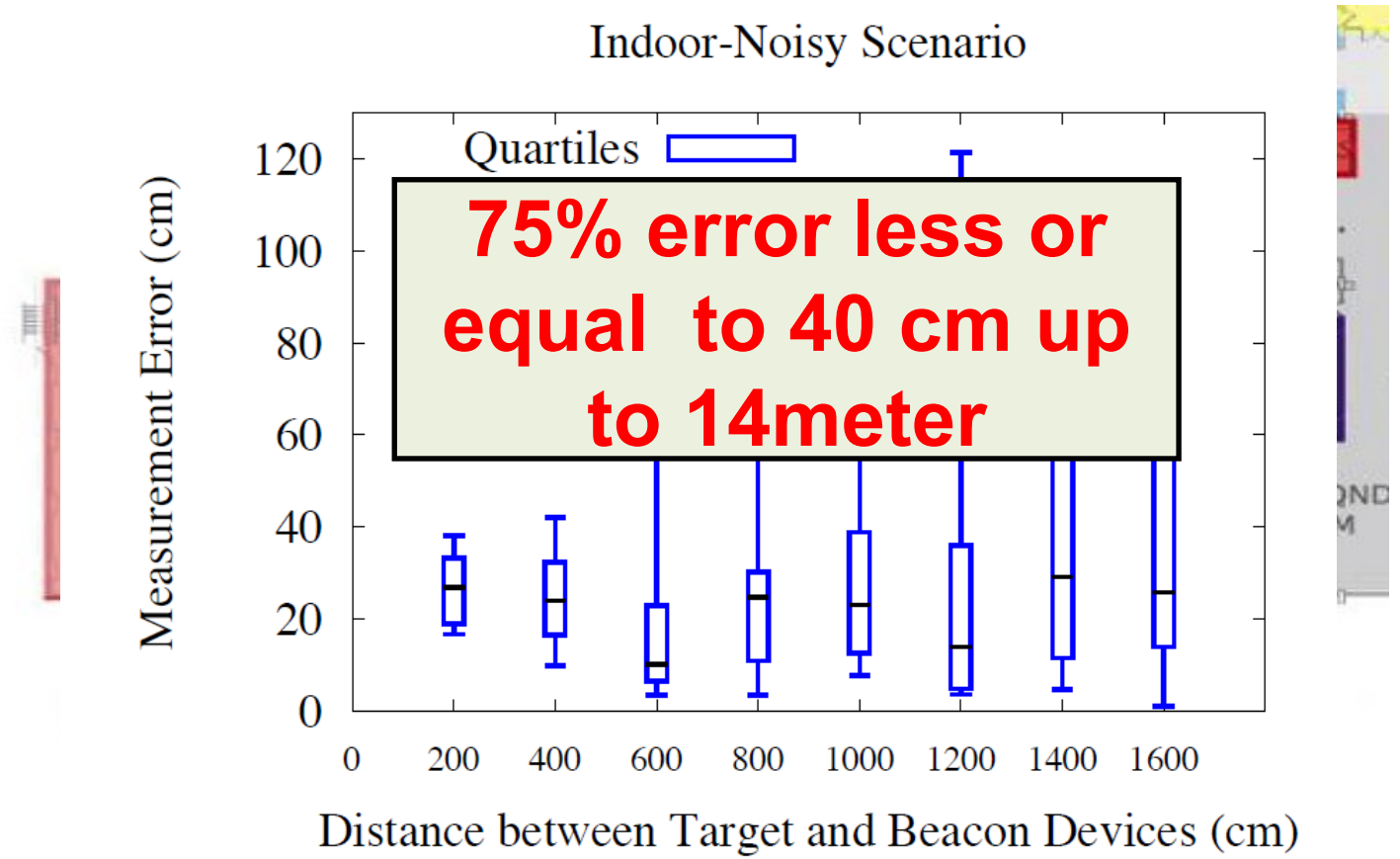
Indoor-noisy

Outdoor-open space



RF-Beep: Evaluation

Indoor-quiet

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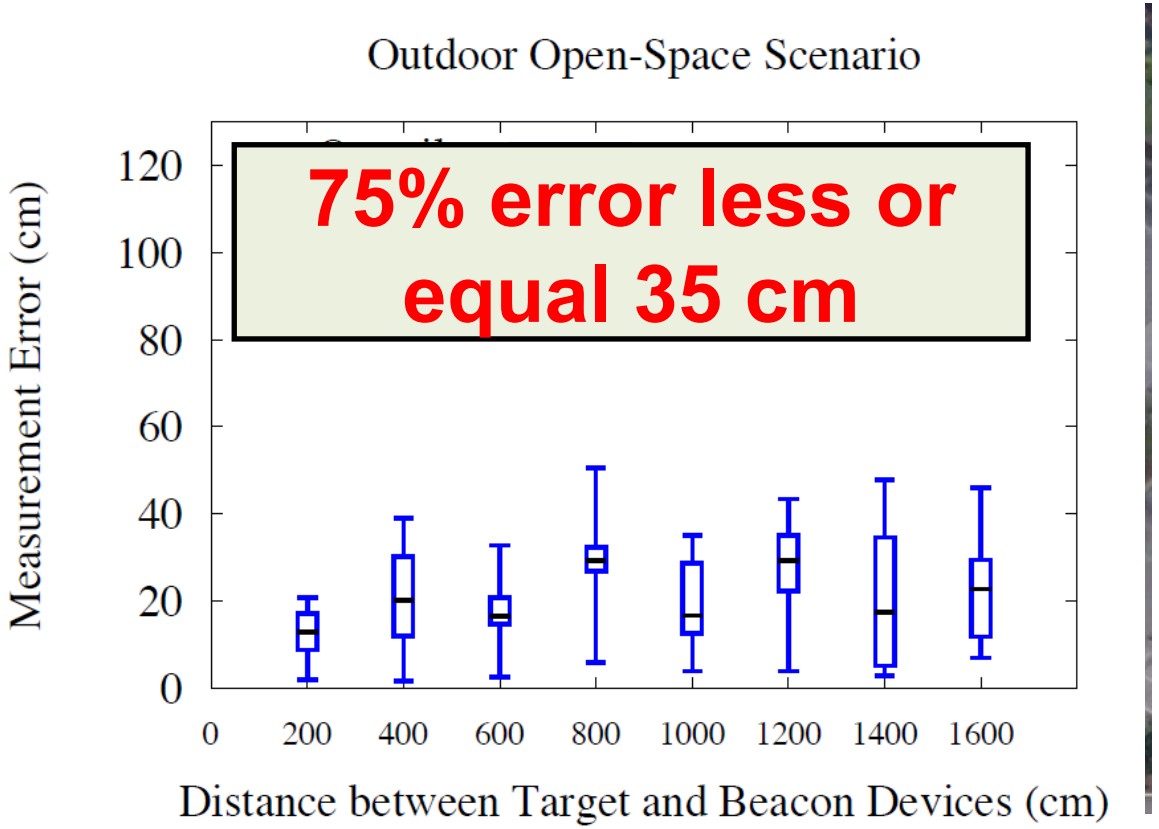
Outdoor-open space



Conclusion

Ranging Scheme: RF-Beep

- One way sensing scheme. (unlike Beep-Beep)
- High accuracy.
- Eliminates time synchronization requirement.
- Smart devices usability. (unlike Cricket)
- Local calculation.
- Energy efficient.
- Privacy preserving. (unlike Beep-Beep)

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