1. Motivation

- WiFi is a common communication interface for smart devices.
- WiFi still has some perturbation such as,
  - Poor utilization of wireless channel.
  - Energy consumption during idle state.
- Unfairness issue due to capture effect.
- Additional channel can be utilized to enhance the performance of Wi-Fi network.
- Smart device can have following interfaces as additional channel:
  - WiFi
  - Bluetooth
  - Zigbee
  - Light/Camera
  - Audio [Can we utilize this interface?]

2. Proposed Idea

Utilize audio channel as an augmented channel to enhance WiFi performance

We like to exploit audio frequency beyond human ear perception as a parallel communication channel with WiFi.

Why Audio communication?

- Non-interferential with radio network.
- No additional bandwidth required from WiFi.
- Speaker/Microphone are very common hardware component in smart device.
- Smart devices are capable of generating and discerning audio frequency beyond human ear

3. Audio-WiFi Network

Preliminary Architecture of proposed Audio-WiFi network

| A-PHY: responsible for signal processing and sending/receiving signal using mic/speaker |
| A-MAC: Can be utilized by MAC and TCP/IP layer to send small size data packet over audio channel. |

4. Preliminary Evaluation work

Sending/Receiving data frames over audio channel

- M-array FSK modulation/demodulation.
- We use 16 frequencies for our modulation/demodulation.
- Each frequency represents a symbol of 4 bit.
- Frequency range from 18000-21200Hz.
- Equal frequency spacing.
- 30bps as data transmission rate.
- Frame size is 25byte.

Packet Error Rate (PER) over different distance

5. Challenges

Technical Challenges

**Challenge 1:** Audio channels suffer from low data rate.

Possible Solution:
- Use audio channel to transmit only small control frames.
- Use different audio tones instead of actual bits for control frames.

**Challenge 2:** Frame-level synchronization between WiFi and audio.

Possible Solution:
- Use single audio frame for aggregated WiFi frames.

6. Ongoing Work

- Utilizing audio channel to enhance the performance of Power Save (PS) mechanism for 802.11.
- Using audio channel as a control channel for sending ACK frames while WiFi is sending data frames.
- Utilizing audio channel for coordinating between node to reduce the collision.

7. Audio-WiFi PS Mode

Association mechanism

<table>
<thead>
<tr>
<th>STA</th>
<th>AP</th>
</tr>
</thead>
<tbody>
<tr>
<td>ListenIntervalTime(0)</td>
<td>If (ListenIntervalTime==0)</td>
</tr>
<tr>
<td>STA has Audio-WiFi Interface</td>
<td></td>
</tr>
<tr>
<td>If (AID&amp;8192==1)</td>
<td>AID (set bit 13th)</td>
</tr>
<tr>
<td>frequency tone = AID+18000</td>
<td></td>
</tr>
</tbody>
</table>

Power Management

- STA turn on the audio interface instead of the wifi interface in each beacon time when it moves to Audio-WiFi PS mode.
- AP will send an audio frequency tone while it has packet for Audio-WiFi STA.

Challenge: Need to determine and minimize the length of the frequency tone.
- STA turn on the wifi interface when it receives certain frequency tone from the AP.

PS-Poll mechanism