The Evolution of Wireless Systems in Pediatric Settings
Evert Dijkstra VP Phonak Communications
Wireless systems for children with hearing loss introduced just 50 years ago

Mark Ross (2003, Access conference Chicago):

- FM systems most significant educational tool developed for hearing impaired children ever developed
- Remain the single most effective way to increase S/N
- The most important factor for speech understanding
- Crucial for adults but even more important for hearing impaired children who are in the process of developing speech and language

Basic principle has not changed. Esthetics, performance, ease-of-use did change
Adoption rates for children are increasing (from toddler to teenager, from Anglo-Saxon speaking to worldwide)
Current state of the art performance of wireless systems

Listeners with hearing loss understand up to 62% better than those with normal hearing.

Dr. Linda Thibodeau, University of Dallas
Wireless systems in educational settings shall ideally offer:

- Zero hassle
- Maximum performance
- Full compatibility

Sophistication with the purpose to simplify!!
Zero Hassle

- Adaptive frequency hopping technology
- Easy connectable receivers and transmitters
- Easy to use interfaces
Frequency hopping principle

- Frequency hopping:
  - Change frequency for each packet in a pseudo random way

- Adaptive frequency hopping:
  - Use the most favorable frequencies by dynamically adapting the sequence

- Different users:
  - Use of different pseudo-random sequences

Frequency hopping makes channel selection obsolete
Interference mitigation

Adaptive Frequency Hopping (Bluetooth, Roger) is the best choice

- Transmitter(s) sniffs continuously whether WiFi is present
- Receiver(s) compute continuously the number of corrupted packets
- Transmitter(s) and receiver(s) exchange regularly data so that occupied spectra can be avoided

Much better than for systems with channels
Frequency hopping systems work @2.4 GHz. This implies:

- Multipath fading phenomenon
- Less transmission through walls
- Less transmission on green-fields

Systems have to be designed to deal with multipath fading
Time, frequency and spatial diversity

Transmit the same signal at different frequencies and at different times and/or use two different spatially separated radio’s.
Roger: implementation of spatial diversity

Used in Roger Soundfield, not applicable in ear-level receivers
Roger protocol

- Time Division Multiple Access (TDMA)
- Flexible allocation of time slots to audio and control
  - One or more audio stream
  - Choice of direction for audio stream
  - Choice of audio stream quality
  - Bi-directional control
Roger protocol: time and frequency diversity for robust communication

- Packet **repetitions in advance** and at different frequencies
- 32 bytes per packet. 64 kbps, giving **8 kHz audio bandwidth** with G722
- **Low delay (latency)**
- Flexible, Bi-directional, allows broadcast
- **Low power** consumption at receiver

If transmission failed 3 times in a row: **Packet Loss Concealment**
Comparison with Bluetooth headset

- Packet repetition **on demand**
- Audio bandwidth: **4 kHz**
- **Low delay** (10-15 ms)
- Limited to point-to-multipoint (**max 3 receivers**)
- **Higher power consumption** at receiver
Comparison with Bluetooth Audio Streaming (A2DP)

- Packet repetition on demand
- Audio bandwidth: **20 kHz**
- **High delay** (~100 ms)
- Limited to point-to-point (**max 1 receiver**)
- **Much higher power consumption** at receiver
Adding devices with «one click connect»

**Connect**

10 cm / 4 Inches

**First slot**
- Contains list of all devices belonging to network
- “Master” transmits pseudo random code to all devices in his network
- Serves as a «beacon»

**Second slot**
- Contains status of all devices
- Contains statistics on link quality
The enabler: a tiny chip dedicated to people with hearing loss

6 million transistors, used in all receivers and transmitters
Summary transmission technology

1. Pseudo-random hopping of frequencies
   - Virtually unlimited number of users
   - Interference free
   - Optimized for low power, high quality audio

2. Differs from Bluetooth by
   - Possibility to transmit 1:N
   - Does not require acknowledgement of receivers (power!)
   - Has much less latency and/or higher audio bandwidth

3. Connect
   - With one click
   - Connect with unlimited number of receivers
   - Connect with unlimited number of transmitters
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Sophistication with the purpose to simplify!!
Maximum Performance

- Adaptive behavior
- Context Dependent Signal Processing
- MultiTalker Networks
Maximum performance: the winning strategy in a nutshell

Enhance SNR in high noise conditions by:

1. **Bringing** the microphone **to the source**, cutting out the distance

2. **Optimizing** SNR at the source with a **beam former**

3. **Adaptively** mixing the wireless microphone signal with the ear-level microphone of the hearing instrument, by increasing the gain of the Roger receiver in higher ambient noise levels

4. **Reducing** the gain when no voice is present
Principle of adaptive mixing: no wireless system

First approximation:
- **Noise** is the same at talker and listener
- **Signal** at listener decreases with 6 dB for every doubling of distance
- **Signal/Noise** ratio easily gets negative
SNR with a non-adaptive system

Compression (keeps input signal constant)

FM signal + HI mic signal = FM + M

SNR @listener has improved but is less than @speaker
SNR with an adaptive gain system

Compression & adaptive gain

SNR @speaker and @listener are equal (copy-paste)
Speech understanding at 5.5 m in various noise levels

- Roger
- Dynamic FM
- Traditional FM

Noise Level (dB(A))

% Correct

Quiet 50 55 60 65 70 75 80

54 % improvement

35 % improvement

N = 11
Reducing gain when no signal is present: voice activity detector

Voice Activity Detector is based on:
- Energy
- Voice metric
- Direction of arrival

As soon as the teacher stops talking, there is no longer a high input level wireless signal.

The hearing instrument microphone is immediately available to effectively amplify the environment and the own voice.
Today’s dynamic classrooms

Group work and Interactive lessons are increasingly important!

Context Depending Signal Processing to maximize performance in all situations

* Derived from internal research, several countries, multiple schools
Small Group Work

**Accelerometer**
- Detects that device is lying on the table
- Changes gain model to Group Work mode
- Enables all three embedded microphones

**Beamforming**
- Beams in 4 different directions are created with the 3 embedded microphones
- The beam with the best SNR is transmitted
- Other beams are mixed with the primary beam as a function of their SNR

Small Group Work mode offers substantial benefits over HA’s alone
Interactive lessons

- Context Depended Signal Processing can also increase performance in pass around microphones, e.g.:
  1. Placed in table stand → increased sensitivity (ideal for reading and signing)
  2. Lying flat on table → muted
  3. Handheld → high performance zoom

- Multi-Talker Network (MTN)
  1. Very Important to increase interactively number of voices to be transmitted simultaneously should be limited
  2. Transmission of 2 out of N voices appears optimal

Pass-around microphones have proven to increase interactivity
Summary maximum performance

Adaptive behavior
- Adapt gain of the wireless system as a function of environmental noise
- Reduce gain of wireless system to minimum of no useful signal present

Context Dependent Signal Processing
- Use context (placement, acoustical environment, etc.) to optimize the signal processing

MultiTalker Networks
- Allows multiple talkers to communicate with hearing impaired child
- New systems allow to transmit 2 voices simultaneously

Performance ultimately determines how well a child can understand and learn
Conclusions: wireless systems do offer

Zero hassle
Maximum performance
Full compatibility

Sophistication with the purpose to simplify!!

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Compatibility

- Generic receivers for all manufacturers
- Compatibility with CI’s and Soundfield
- Multimedia connections
My greatest acknowledgement goes to all staff members @Phonak Communications in Murten (Switzerland) and Halmstad (Sweden) for their full dedication to wireless technology for the hearing impaired.
Thank you