Replacing Cables: Intra-Vehicular Data Broadcasting via the Audio Infrastructure

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Abstract

Intra-vehicular communication of sensor outputs and control unit signals are currently handled via cables. Due to the weight and safety issues associated with cables, the automotive industry aims to transfer as much signaling as possible to the wireless domain. However, wireless RF communication is prone to jamming and eavesdropping . The wireless spectrum is also scarce, and issues with interference and contention hinder reliable low-delay communication. To address these issues, we used the vehicle's existing speaker system to communicate part of the intra-vehicular signaling. This approach uses the 18 – 23 kHz frequency range to transmit the sound signal, which is **inaudible** to the human ear. On the transmission end, the signal output that is originally connected to the cables, is encoded, modulated, and broadcasted through the speaker. On the receive end, the targeted device is equipped with a small microphone to collect the desired data signal, which is then demodulated and decoded accordingly. To reduce the error rate, we implemented and tested different channel coding techniques, and achieved reliable transmission of data at rates up to 2.94 kbps. We also implemented OFDM to further improve the data transmission rate. Our approach reduces the usage of cables in vehicles, thus reducing their weight. It also uses the existing audio infrastructure to provide reliable and safe communication without the use of wireless RF transmissions.

Introduction

Motivation

- Reduce the amount of cables in vehicles:
  - Reduce cable length
  - Decrease maintenance costs
  - Reduce weight
  - Improve safety
  - Increase security

Other Technologies

- Wireless (ex, Bluetooth, ZigBee, etc.):
- Open to jamming and eavesdropping, leading to system hack
- Interference with existing vehicular communication
- Potential interference with vehicle operation

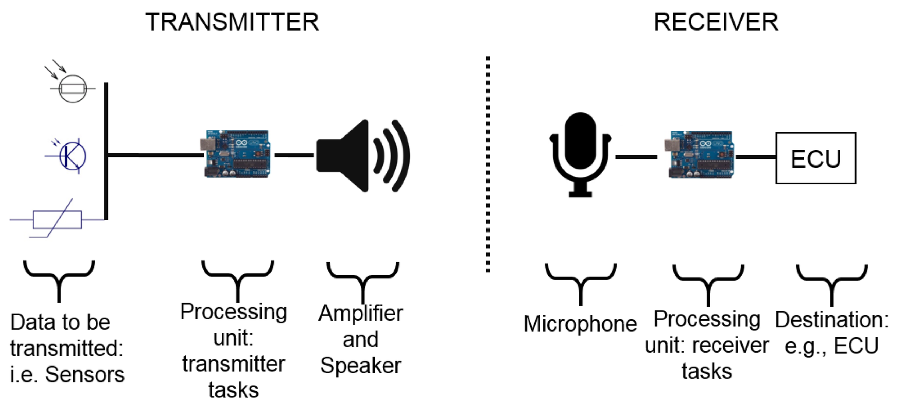
- Vehicular Power-Line Communication (PLC)
- Safety regulations due to extra load
- Noisy and highly frequency selective transmission channel
- Easy to wiretap

Objective

Achieve reliable (low error and delay) transmission of intra-vehicular units data using the vehicles audio infrastructure

Methodology

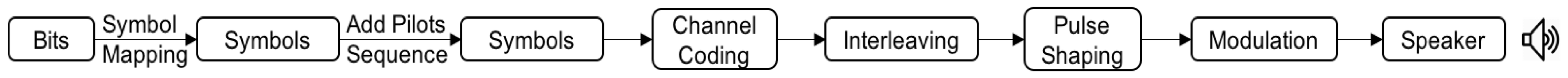
- A communication system was designed on software for data broadcasting and receiving
- The system was implemented on a processing unit



- For testing inside the vehicle, a laptop was used as the processing unit.
- Data was generated randomly and then broadcasted through the vehicles audio infrastructure

Communication System Design

Transmitter



Receiver

Pulse Shaping

- **Implemented:** Raised cosine pulse – Nyquist pulse
- Matched filter at the receiver to prevent ISI

$$H(f) = \begin{cases} T, & |f| \le \frac{1-\beta}{2T} \\ \frac{T}{2}\left[1+\cos\left(\frac{\pi T}{\beta}\left[|f| - \frac{1-\beta}{2T}\right]\right)\right], & \frac{1-\beta}{2T} < |f| \le \frac{1+\beta}{2T} \\ 0, & \text{otherwise} \end{cases}$$

Synchronization, Channel Estimation, Frequency and Phase Recovery

- Uses known pilots integrated in data symbols.
- **Implemented:** Combination of symbol and frame sync at the sample level
- We can control the synchronization accuracy via the sampling rate (20 μs with the current implementation)

$$\hat{\tau}_{\text{Moose}} = \arg\max_{n} \frac{\sum_{i=K-1}^{N_p-1} \tilde{y}[n+i+N_p]\tilde{y}^{*}[n+i]}{\sqrt{\sum_{i=K-1}^{N_p-1}|\tilde{y}[n+i+N_p]|^2}\sqrt{\sum_{i=K-1}^{N_p-1}|\tilde{y}[n+i]|^2}}.$$

- Frequency and phase recovery is done simultaneously following channel estimation

Channel Coding

- Allows data transmission to be more robust to disturbances present on the transmission channel
- **Implemented and Tested:** Linear block codes (7,4), (7,3), (3,1) codes
- Example: (7,4) code

$$\underbrace{\begin{bmatrix}1 & 0 & 1 & 0\end{bmatrix}}_{k \text{ input bits}} \underbrace{\begin{bmatrix}1&0&0&0&1&1&0\\0&1&0&0&1&0&1\\0&0&1&0&0&1&1\\0&0&0&1&1&1&1\end{bmatrix}}_{k\times n \text{ generator matrix}} = \underbrace{\begin{bmatrix}1&0&1&0&1&0&1\end{bmatrix}}_{n \text{ encoded bits}}$$

Modulation

- **Implemented:** BPSK and QPSK

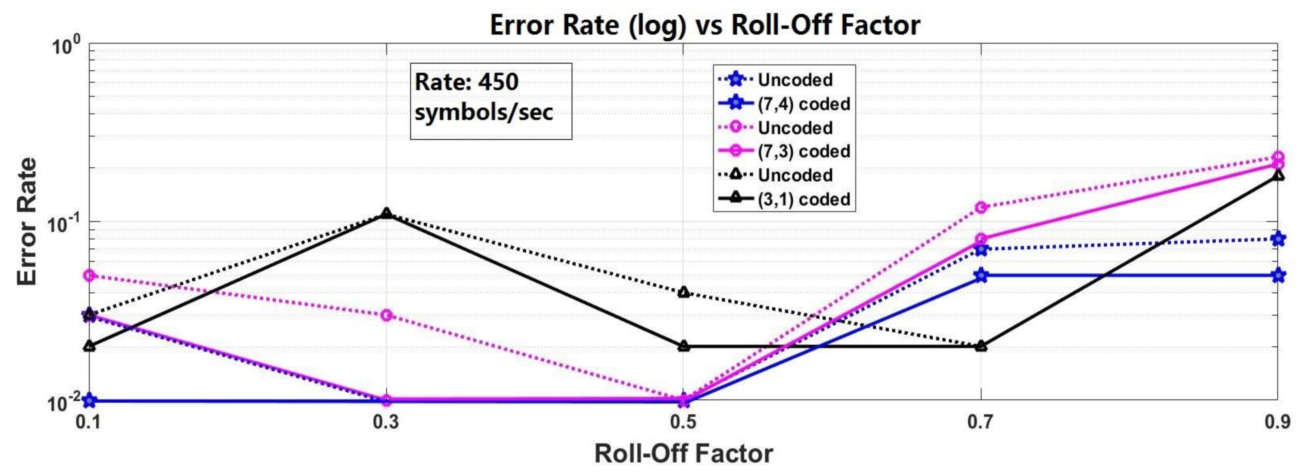
Wideband Communication – OFDM

- We observed the need to handle wideband setting
- **Implemented:** Multiple orthogonal subcarrier frequencies. Converts multi-tap channel into several single-tap channels

Results

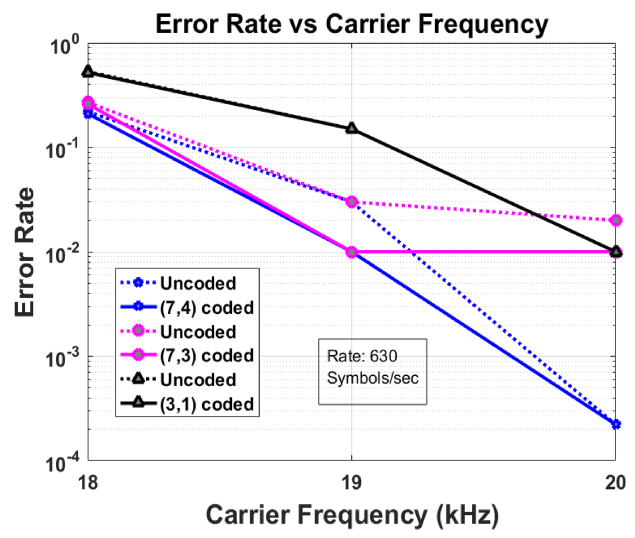
Roll Off Factor test results

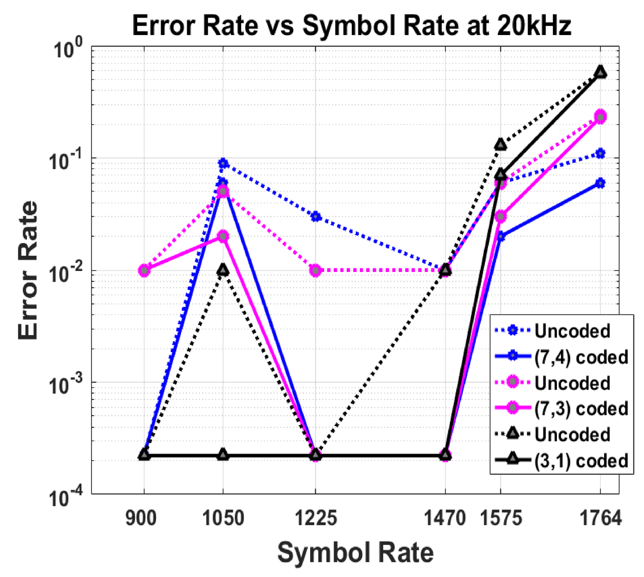
- QPSK modulation
- Symbol rate: 450 symbols/sec
- Error shown with and without channel coding



Channel Coding test results

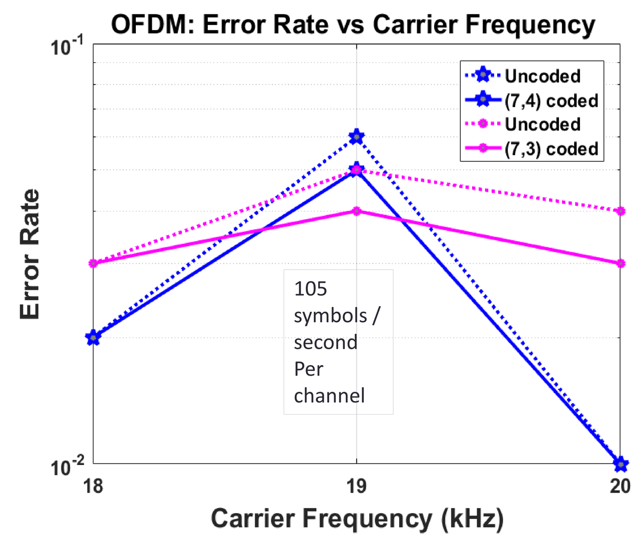
- QPSK modulation
- Error shown with and without channel coding

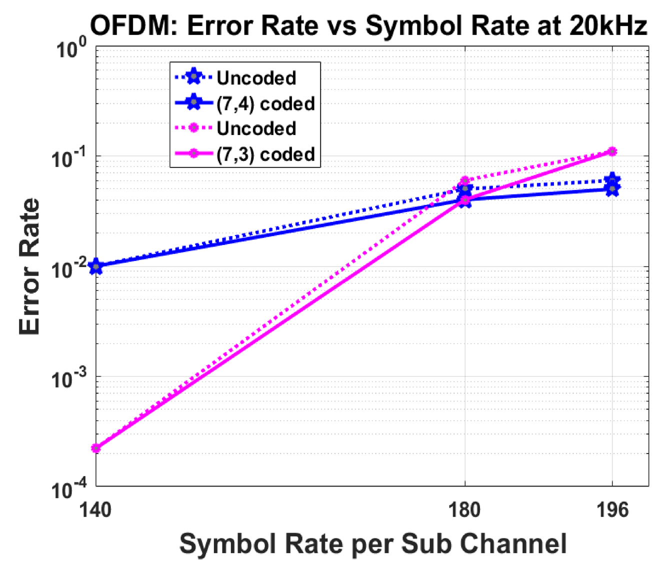




OFDM with Channel Coding test results

- 5 sub channels
- BPSK modulation
- Error shown with and without channel coding





Discussion

- The Roll off factor (β) was chosen to be 0.5 since it gave the least error
- When testing different carrier frequencies, 20 kHz resulted in the most reliable data transmission
- Block codes (7,4) and (7,3) best allowed the data to be more robust to disturbances
- At carrier frequency of 20 kHz, reliable communication (~0% error) of 1470 symbols/sec (2940 bps) was achieved
- Higher reliable transmission rates were achieved without implementing the OFDM system
- More sub channels and larger block codes would improve the transmission rates of the OFDM system

Conclusion

Advantages of our system

- With transmission rate of 2.94 kbps, many vehicle units and devices could communicate through the audio infrastructure instead of cables
- Existing audio infrastructure is high-end and it provides high-quality sound
- Portion of non-audible frequencies are well within the dynamic range of the current speaker/mic components. Also, wideband is possible
- Naturally secure - difficult to eavesdrop and jam by external attackers
- Does not cause additional interference to the already congested wireless RF spectrum

Disadvantages of our system

- Noise levels are highly variable and dependent on the situation (mobile, static, highway, busy roads, etc.)
- Advantage only for the components that are close to a speaker. For others, cables are required

Future Steps

- Extensive evaluation with built in hardware under a variety of conditions (with mobility, exterior noise, etc.) to achieve:
  - Low Power Consumption
  - Robustness with respect to variable conditions
  - Long lifetime
  - No disturbance to existing systems
- Expand the set of codes to a more robust larger block codes
- Examining efficient placement of speakers and microphones to reduce costs

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References

[1] Y. O. Basciftci, F. Chen, J. Weston, R. Burton, and C. E. Koksal, "How vulnerable is vehicular communication to physical layer jamming attacks?," Proceedings of IEEE Vehicular Technology Conference, VTC 15, Boston, MA

[2] Koksal C. E. and Ekici E., "Cognitive Audio: Silent Multi-Audio-Signal Broadcaster without Wireless Transmissions," Invention Disclosure, Ohio State University, Dec. 2015