Long-range Near Field Communication for Ultra-dense Internet of Things

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Introduction

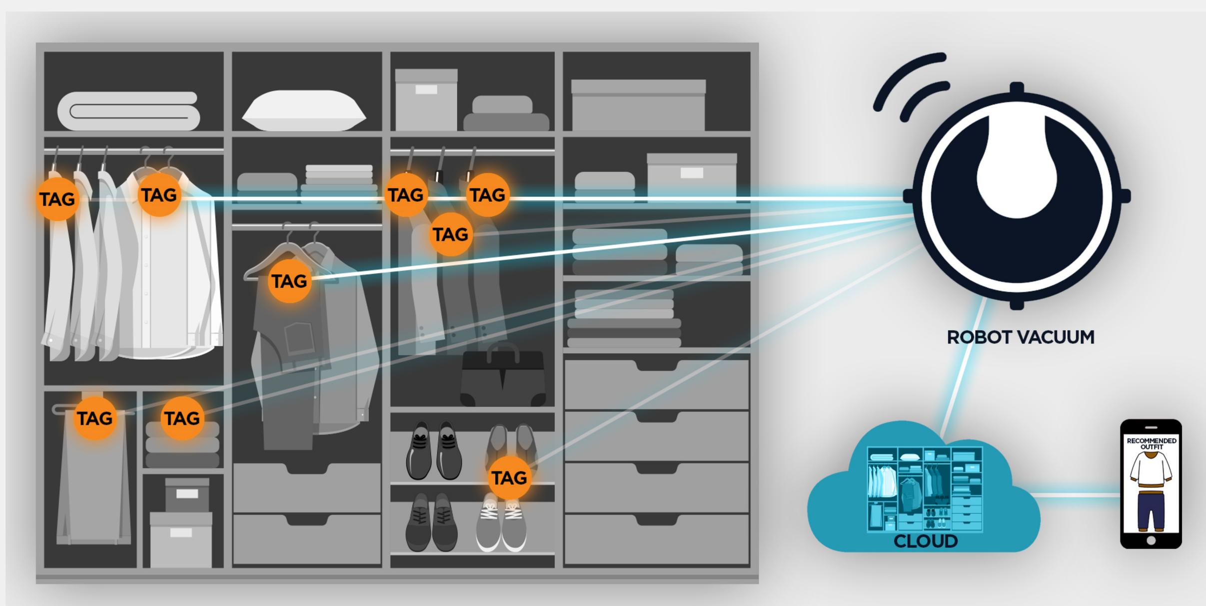


Figure 1. Digital Twins of Smart Home with Internet of Everything (courtesy of Joel Brehm).

- 6G wireless systems will create a digital world with applications in the metaverse, extended reality, holographic-type communications, etc. [1]
- It is essential to network everything in our daily lives in order to create accurate digital twins of the physical world.
- With digital twins, Artificial Intelligence (AI) can be used to help us manage our lives, e.g., tracking, recommendations, among others.
- Fig. 1 is an example where everything can be tagged, and AI is used to recommend outfits.

NFC vs RFID

- Objective: Tag everything in an ultra-dense setting with tag coupling and a complex environment.
- NFC: 13.56 MHz, ISM band. We consider ISO 15693 as a part of NFC standards.
  - Long wavelength⟶ penetrate most everyday things
  - Signals fall off fast⟶less interference
  - Short communication range ⟶better localization accuracy
  - Highly secure
- RFID: UHF band is widely used.
  - Short wavelength ⟶ signals experience multipath fading; cannot penetrate inhomogeneous media.
  - Cannot reliably read tags in complex environments with a large number of tags.
  - Compete for spectrum with other UHF applications around 915 MHz.

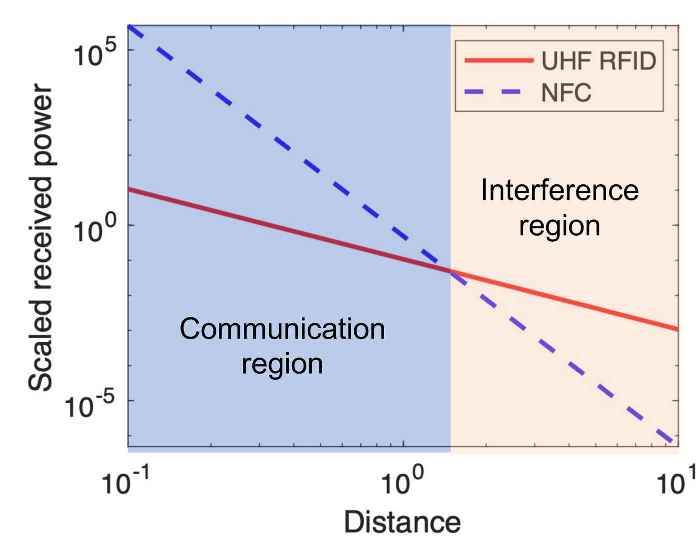


Figure 2. The scaled received power of UHF RFID and High Frequency RFID/NFC.

Existing NFC Standards

- Existing NFC coils use a quality factor around 8 to obtain a bandwidth of 1.696 MHz.
- This allows users to use one NFC coil for multiple international standards, including ISO14443, ISO15693, and ISO18000.
- ISO14443 can support data rates of 848 kbps which requires a broad bandwidth.
- ISO15693 can support 6.62 kbps. It has a longer communication range.
- We select ISO15693 as the standard and investigate the potential approaches to extend NFC's communication range.

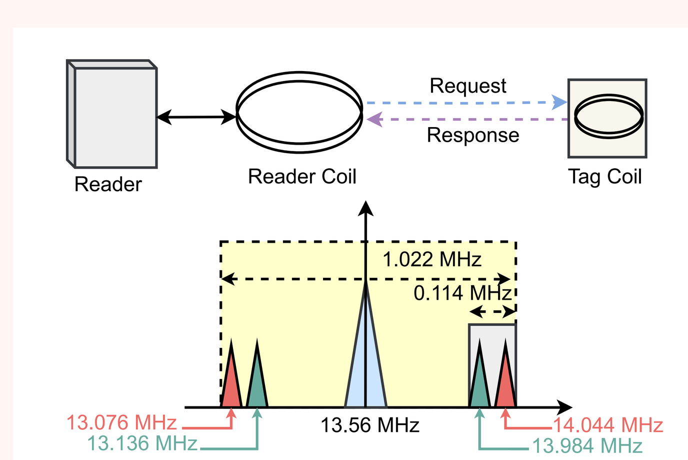


Figure 3. Illustration of ISO/IEC15693 communication systems. An example of the spectrum is given in the lower part.

Separated Transmitting and Receiving Antennas

- Separating the transmitting and receiving coil antennas can provide flexibility in designing individual coils [2].
- Transmitting coils operate at 13.56 MHz, while receiving coils receive signals at around 14 MHz due to subcarrier modulation.
- Design transmitting and receiving coils with a high quality factor and resonate at different frequencies.

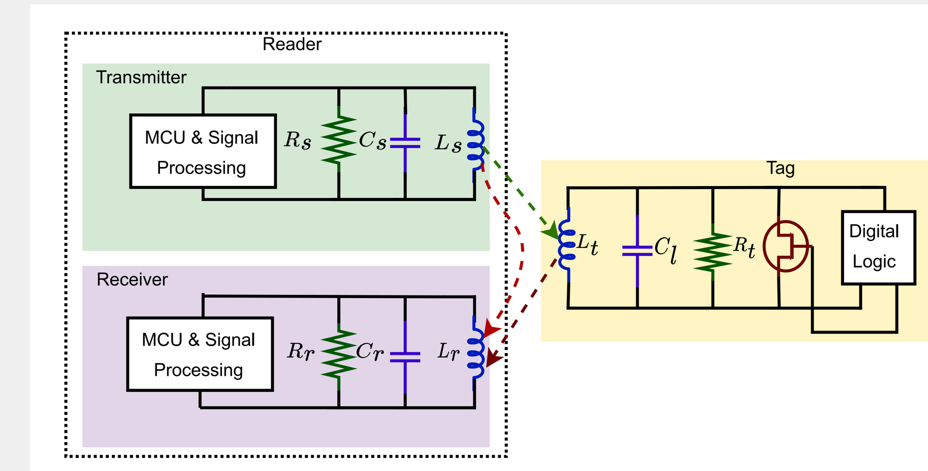


Figure 4. Equivalent circuit model of the modified NFC system with separated transmitter and receiver circuits in a reader.

- There is a self-interference problem: the receiving coil receives a signal from the transmitting coil that is much stronger than the signal received from the tag.
- Utilizing signal processing and filters can effectively reduce self-interference [2].

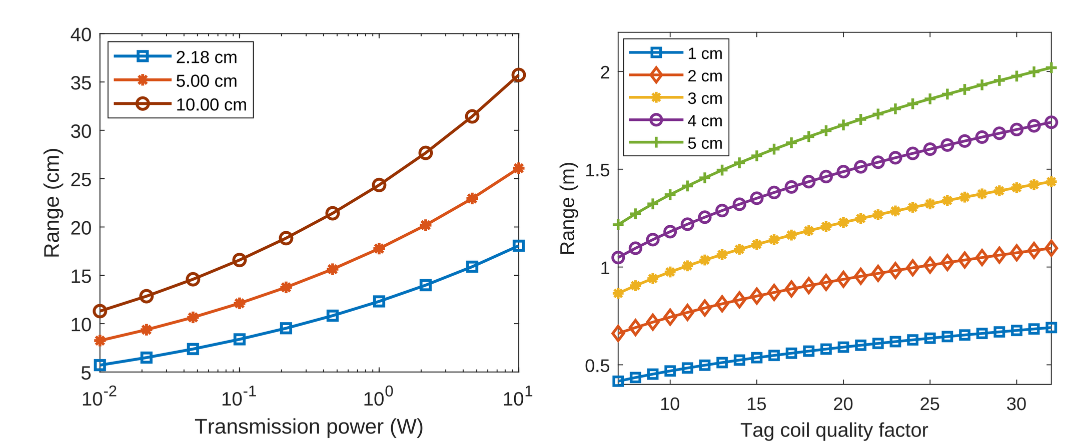
Communication Range

The maximum communication range is

$$d_{st} = \frac{r_s^{\frac{2}{3}} P_t^{\frac{1}{6}} Q_s^{\frac{1}{6}} (4\cos^2\theta + \sin^2\theta)^{\frac{1}{6}}}{\sqrt[3]{4 h_{min}\sqrt{\pi f}\sqrt{\mu_0 r_s [\ln(8 r_s/w_s) - 2]}}}.$$

r_s is the transmitting coil radius, P_t is the transmission power, Q_t is the transmitting coil quality factor, θ is the polar angle of the tag's location when transmitting coil is at the origin of a Spherical Coordinates System, h_{min} is the minimum magnetic field strength, f is the frequency, μ_0 is the permeability, and w_s the radius of wire.

- Existing NFC has a communication range of 5 cm.
- Increasing the transmission power and the size of the transmitting coil can extend the communication range by 7 times.
  - Transmission power: 8 W, transmitting coil radius: 10 cm.
- Increasing the quality factor of the tag coil can further increase the communication range by 4 times, resulting in an overall increase of 28 times.
  - Tag coil radius: 3cm, quality factor:32.

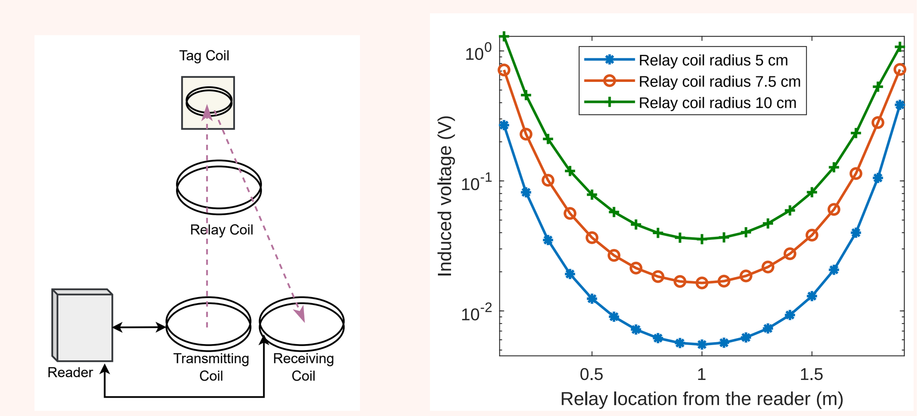


(a) Impact of transmission power. (b) Tag size and quality factor.

Figure 5. Extended communication range with separated transmitting and receiving coil and modified tag coils.

Relay Coils

- Relay coils can be placed between the NFC reader and tags.
- For example, in a closet or kitchen, relay coils can be embedded into the closet or under the countertop. Tags can be attached to clothes or food bags.
- The transmitting coil and tag coil are separated by 2 m. The location of a relay coil varies from 0.1 m to 1.9 m.
- When the relay coil is very close to the transmitting coil or tag coil, the induced voltage can be strong enough to power up the tag coil.

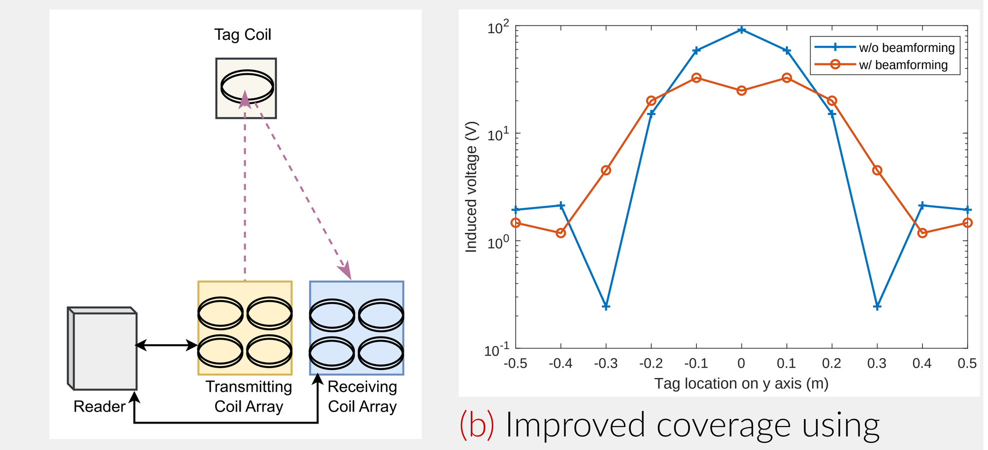


(a) Coil relay. (b) Impact of relay location.

Figure 6. Coil relay and extended communication range.

Magnetic Beamforming

- Multiple coils can be used to form a coil array.
- Magnetic beamforming can be used to improve reliability by reducing misalignment loss.
- The location of a tag coil is varied horizontally from -0.5 m to 0.5 m. The center of the reader coil serves as the origin of the Cartesian Coordinate System.



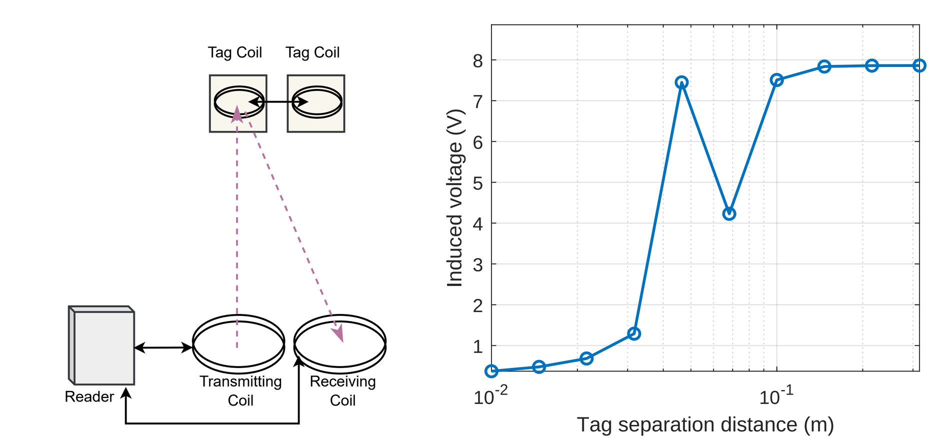
(a) Coil array. (b) Improved coverage using magnetic beamforming.

Figure 7. Coil array and magnetic beamforming.

- Magnetic beamforming cannot improve the range due to bandwidth limitations but can reduce misalignment loss.

Tag Coupling in Ultra-dense IoT

- In ultra-dense IoT, tags are placed close to each other, and their coupling can significantly reduce the range.
- In the figure on the right, two tags are positioned closely. One tag's location is fixed, while the other tag's location varies from 1 cm to 31.6 cm from the center of the first tag.
- When the distance between the two tags is smaller than their radius, the two tags are stacked together.



(a) Tag coupling. (b) Impact of tag coupling.

Figure 8. Illustration of tag coupling and the negative impact on the induced voltage.

- When the distance is smaller than 3 cm, the voltage is low, and communication is impossible. There must be a density requirement to avoid excessive coupling.

Conclusion

Ultra-dense Internet of Things plays an important role in the Internet of Everything, which is an essential technology for developing digital twins. In this work, we explore three techniques to extend the communication range and reliability of NFC: high-quality factor coils, relays, and magnetic beamforming. The communication range can be influenced by misalignment and strong coil couplings. Analytical models have been developed to evaluate these approaches and their potential negative impacts. The results demonstrate that NFC communication range can be increased up to 2 m.

Acknowledgment

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References

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[2] Renjie Zhao, Purui Wang, Yunfei Ma, Pengyu Zhang, Hongqiang Harry Liu, Xianshang Lin, Xinyu Zhang, Chenren Xu, and Ming Zhang. NFC+ breaking nfc networking limits through resonance engineering. In *Proceedings of the Annual conference of the ACM Special Interest Group on Data Communication on the applications, technologies, architectures, and protocols for computer communication*, pages 694–707, 2020.