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Reconfigurable Intelligent Surfaces (RIS) for Next Generation 6G Wireless Technology

Introduction

Reconfigurable intelligent surfaces, or RIS, is a technology listed on the World Economic Forums's top 10 of 2024 list for emerging technologies to watch. This technology has demonstrated usefulness in the next wave of wireless communication and can be implemented in many ways, such as attaching the RIS to exterior or interior building walls or structures. RIS could be a multitude of small antennas mounted on a surface or some other metastructure that can dynamically affect radio waves based on real time needs. Effectively, RIS transforms the "wireless channels into a software defined environment." (Wang et al, 2022).

RIS technology is touted as cost effective, can be used with less interference (noise or self), and whose configuration can be changed as needed in comparison to existing wireless communication technologies such as MIMO relays, conventional relays, and backscatter communication where they are typically more costly, use more energy, have more interference, and are static once constructed (Basharat, 2021). RIS has the potential to usher in the 6G wave of wireless technology (a.k.a smart radio environments) to meet the growing demands of increased wireless device usage.

Technical Summary

Introduction

The IEEE Journal on Selected Areas in Communication published an article titled "Smart Radio Environments Empowered by Reconfigurable Intelligent Surfaces: How It Works, State of Research, and The Road Ahead" in 2020 by Di Renzo et al. The article describes the current wireless communication environment, the shifting paradigm of thought toward emerging technologies such as RIS, scenarios for it's use, a deep structural/technical analysis of how the technology works, and some challenges researchers face in its application.

Description

Di Renzo, et al. outline their goals of the paper within the first page: the definition and prototype examples of reconfigurable intelligent surfaces, what exactly it is and what it does, the mathematical theories behind the technology, descriptions of many different applications, and the state of the research including challenges. The main problem of current wireless technology is the problem of increasing data traffic and the limitations of 5G technology. The authors describe how current communication models are at the mercy of the environment (weather, location of equipment, obstacles) and radio waves cannot be controlled or customized after transmission, but RIS is a promising avenue to change this in the future. An example given of a prototype RIS is from NTT's DOCOMO project where they have created "smart glass" that contains a RIS structure covered in glass, which allows dynamic control of radio wave response; however, it's noted that there are many ways this technology can be designed and implemented. The authors describe how RIS is typically passive, reflects existing waves without creating more (reflective), can be integrated into the environment (structures) and is environmentally sustainable. Some examples include smart buildings where the RIS "smart glass" can enable indoor to outdoor connectivity, enhance coverage to reach more users, and can be integrated into windows. There is also wireless power transmission capability and aerial transmission capability with RIS, which are other promising avenues of research.

Analysis

This paper is very in-depth and geared toward a highly technical audience; however, the paper is well designed and accessible for a wider audience to understand reconfigurable intelligent surfaces at a high level before diving into the math and physics of the structures themselves. While the mathematical and scientific theory portions are not my area of expertise, the descriptions of the dynamic capabilities of RIS technology, the applications provided, as well as the challenges are thoroughly described and it's easy to see how this technology could be used within the next generation of wireless technology. Visualizing a future where static structures are covered in an intelligent material that aids in communication seems realistic and not too distant.

The important aspects of RIS from this article are its ability to seemingly be integrated into the existing environment of wireless communication without creating more interference or losses, plus the cost effective and sustainable nature of the materials being used to date are a plus. The mention of it's use for wireless power transmissions is very compelling as a side note. Imagining smart glass or some other surface material that can be used to replace building windows, to cover exterior or interior structural walls, or similar applications is useful to know since it could be used with existing infrastructure versus only with new buildings. Tack on wireless power and you might eliminate the need for all the utility poles and underground infrastructure in some areas like cities. The authors also mention using machine learning to allow the structures to dynamically change with the needs of the environment. Most of the descriptions make all of this sound wonderful; however, some of the research challenges include accurate modeling for losses and performance limits, large scale deployment production and costs, and security.

Conclusions

The application of reconfigurable intelligent surfaces is very compelling and there are working small-scale prototypes for it. While more research is needed to fully examine the real-world gains and optimization from its use (dependent on how it's constructed and implemented), it's easy to see a future where this technology is everywhere.

Use Case Analysis

Engineering the next generation (6G) of wireless communication is one use case for reconfigurable intelligent surfaces. According to the World Economic Forum report on the top 10 emerging technologies of 2024, the United States alone is investing over 43 billion dollars between 2021-2023 (2024). The aim of using RIS for 6G wireless is to namely to meet the demand of growing wireless needs that are not solved by 5G and earlier wireless technology. The ability of RIS to dynamically change with software defined and machine learning capable configuration, it's cost effective and energy efficient nature, and its ability to be adaptable to the structure/environment currently available make it an exceptionally promising avenue of research. The prototypes of "smart glass" by NTT and also MIT prototypes demonstrates the real-world application on a small scale (Di Renzo et al, 2020).

Benefits

Basharat (2021) states the benefits: "compared to conventional relaying that requires additional power for signal transmission, amplification, and regeneration, RIS passively reflects the impinging signal by inducing intelligent phase-shifts, without the need for additional radio frequency source." Conventional, mMIMO, and backscatter communications are rigid in that once they are installed, there is no modification. A line of sight is also typically required in order to receive the signal and RIS promises to go around obstacles while also amplifying the signal. Practically speaking, this technology would integrate into existing infrastructure or work with other emerging communication technology to extend and amplify coverage for 6G wireless networks therefore meeting the increasing demand. The energy consumption of RIS is also substantially lower than these existing technologies (Wang et al, 2022).

Risks and Concerns

Some risks include security as with all networking and wireless communication. Riveti et al (2024) note a risk in the physical security layer by implementing malicious RIS, which Wang breaks down into two main security concerns: signal leakage and interference attack (2022). While the amplification of radio waves is the key benefit for 6G, there is also the risk of eavesdropping or jamming since it's aim can be changed and directed to any one base station, individual, or the like. Riveti demonstrates the ability for a silent attack to occur by introducing a malicious RIS structure into the path of another RIS and also a means of countering it. With the thought that this technology could be covering buildings or be embedded in glass in a smart city or within vehicle windows, the potential for rogue devices and their impact can be much greater.

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As Wang notes, more research is needed in the physical security layer to counter the security risks present (2022). Some suggestions are to adopt deep reinforcement learning/neural networks to be able to detect signal leakage or interference. Di Renzo notes more work is needed to determine the appropriate composition of the intelligent surfaces and more realistic models for how signals are scattered/reflected by these surfaces (2020). Essentially more needs to go into the real-world application to determine if it will indeed meet the needs of 6G wireless networks.

Another key engineering consideration to be explore is the degradation of the materials. There is no mention of the longevity of these surfaces in the journals reviewed. While they may be low cost, what is the scale required, and what happens if one smart window stops functioning or the wallpaper like structure covering rips or degrades? Does one window degrade the entire system or will everything continue as normal? Certainly with the potential for a smart city as an example of its use, more thought is needed on the long term viability of materials being used in addition to performance.

Critical Engineering Policy Brief Recommendations

While there is substantial investment by the United States and other countries into the research and development of reconfigurable intelligent surfaces, there must also be consideration of how this will change future communications infrastructure and what that will mean for consumers, network providers, and existing infrastructure. Three main concerns are evident in the current research: (1) network physical layer security (Wang et al, 2022), (2) availability for a diverse population beyond limited use cases, and (3) real world performance results to ensure consumer safety and longevity (Di Renzo et al, 2020).

While research has been ongoing for many years, there is a lack of literature on the performance of RIS technology in the real world and a lack of large scale prototypes. Smart cities are often mentioned; however, if this technology can plug holes in dead zones and provide access to more people, there is work to be done to demonstrate how it will be implemented by network providers to accomplish this. With all the ways RIS can be integrated into material, such as smart glass, and it’s ability to be integrated into other technology such as autonomous vehicles for wireless connectivity, consumer safety concerns must also be considered.

- **Address physical layer security**
  The aim of larger scale prototypes is to narrow down and showcase the use of the technology and determine it’s impacts on the wireless environment in a controlled way

mirroring how it will be used in larger applications such as interior and exterior surface coverings. Mimicking how physical layer security is effectively handled in a large scale prototype will go a long way in ensuring future development and commercial production is already ahead of the security curve and not subjecting the communication infrastructure to potential jamming or interference attacks (Wang et al, 2022), which could be a safety concern if used in moving vehicles that require this technology for communciation.

- **Consider availability outside limited use cases**
  With the potential for changing the wireless landscape, policy makers and researchers must work with network providers early on to not only demonstrate the technology, but figure out how this will be used for the benefit of not only smart cities, but for people living in low coverage areas. Cities already have better coverage than rural areas, so ensuring equal access to the benefits of expanded wireless communication is paramount for each new generation of technology. Each subsequent generation of wireless should be increasingly accessible and R&D efforts should take into account how available this could be for consumers as well as network providers early on.

- **Focus on real-world performance results**
  The real cost of production and ownership and it's expected gains need more concrete results and policy makers can ensure that funding is directed toward this. If RIS is to be integrated into our daily lives and its critical to meet increasing demands, there needs to be a real assessment of how that looks by narrowing down a chosen implementation and exploring what that looks like in the real-world. Another benefit is determining the longevity of material and how it performs in various environments (weather, temperature, damage) to ensure that wide-scale use does not cause problems like increased outages affecting everyday life. This will go a long way in ensuring safety for consumers when smart glass becomes common in vehicles, buildings, and/or homes.

Final Thoughts

The potential for reconfigurable intelligent surfaces to change the wireless landscape and allow for seamless integration with existing infrastructure, other emerging communication technologies, and to offer more wireless coverage and capacity is paramount to meeting increased wireless needs across the globe. Focused research and development with demonstrated real-world benefits is the first step to realizing a future where RIS is integrated into everyday life and available not only in smart cities, but for a wider audience.

Continued communication, development, and aligned action with network providers and researchers allows for challenges such as cost of ownership, longevity, security and other considerations, important to not only governments and corporations but also everyday individuals, is considered and thought out to minimize disruptions to technology that is increasingly a part of everyday life for many.

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