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HYPERLOOP COMMUNICATION

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Abstract: High-Speed rail(HSR) communication has always been an attractive research topic with the continuous progress of transportation systems and communication technologies. Recently, Hyperloop has emerged as a candidate for very high-speed transportation systems. Because of its outstanding potential, Hyperloop can usher in a new transportation era with several attractive features. Developing suitable communication system solutions is crucial to bring this promising technology closer to reality. The Hyperloop communication system is essential to support monitoring-and-controlling services and deliver communication services inside its capsules/pods. It must be studied to determine if existing HSR communication technologies can establish robust communication links and deliver data with the required QoS.
Keywords: HSR, Hyperloop, transportation, communication technologies, monitoring, controlling, QoS.

I. INTRODUCTION

Hyperloop is a futuristic transportation technology that promises to revolutionize the way people and goods are transported. The technology was first proposed by Tesla and SpaceX CEO, Elon Musk, in 2013, and has since gained considerable attention from various stakeholders in the transportation industry.

Hyperloop communication system is an advanced version of the hyperloop technology that incorporates communication and networking capabilities into the system. It is designed to provide high-speed, low-latency, and secure communication between hyperloop pods, stations, and other network endpoints.

The hyperloop communication system uses a combination of advanced networking technologies, such as 5G and satellite communications, to provide reliable and high-bandwidth connectivity to hyperloop pods and other network endpoints. This enables hyperloop pods to communicate with each other and with ground-based stations in real-time, allowing for efficient control and management of the hyperloop system.

The introduction of the hyperloop communication system is expected to bring numerous benefits to the transportation industry, such as faster transportation, reduced congestion, and improved safety. Additionally, the technology is expected to have a significant impact on various industries, such as logistics, healthcare, and manufacturing, by enabling faster and more efficient transportation of goods and services.

Overall, the hyperloop communication system is a promising technology that has the potential to transform the way we transport people and goods, and to provide new opportunities for innovation and growth in various industries.

II. HYPERLOOP STRUCTURE

Elon Musk's Hyperloop is an innovative transportation system that consists of a sealed vacuum tube within which a capsule or pod, levitates and moves at a very high speed. It is self-powered and environmentally sustainable, consuming renewable energy. Simulations were conducted to investigate the energy consumed by Hyperloop as a function of the speed of the pod and pressure inside the tube, and to optimize the pressure in order to minimize energy usage. The two main components of Hyperloop are the tube and the capsule, which can carry 25 to 40 passengers. The tube is an evacuated cylinder with a diameter of approximately 3 m and is made of steel with or without concrete. The capsule is optimally designed to levitate and float inside the tube, enhancing its speed and performance.

III. HYPERLOOP OPERATION

A. *Levitation:* The Hyperloop does not need wheels to move forward. Suspension or levitation allows the pod to float inside the tube, counteracting the effect of gravitational acceleration. Two main ways to maintain the pod suspended in the air are magnetic levitation and air bearing. Magnetic levitation relies on magnetic fields using

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superconducting electromagnets, while air bearing involves pressurized air lifting the weight of the moving surface. In both scenarios, gravitational acceleration is compensated and the pod does not undergo ground friction, resulting in a tremendous increase of its speed.

B. *Evacuated Environment:* The pod travels in a low-pressure vacuum-sealed tube enabling land transportation to approach sonic speeds. The idea was to eliminate the air creating an almost air-free environment and drastically reducing the pressure. Devices called vacuum pumps remove the air from the sealed tube to maintain the desired atmospheric pressure and deal with gases leakage that eventually occurs along the tube from connections. The optimal pressure must be computed since higher pressure inside the tube requires less energy for the pumping system but at the same time, drag forces increase and energy required for propulsion increases.

C. *Propulsion:* Propulsion is the action of pushing objects forward as a result of thrust generated by dedicated engines. In the case of Hyperloop, only intermittent propulsion is needed due to the levitation and evacuated tube. An electric linear motor system, powered by solar panels, is used to propel the pod and keep it running at the intended speed of 1200 km/h. The propulsion system is fully electric and does not use any fossil fuels, further supporting the sustainability of Hyperloop. Research papers have studied the propulsion system that can counteract air-resistance.

IV. NETWORK ARCHITECTURE

Hyperloop is a combination of a train and a tube, making its communication network architecture different from those of conventional HSR systems. The tube is partially or wholly made of steel, so an external signal cannot penetrate its walls without significant losses. Therefore, a suitable design of communication links is necessary to establish successful train-to-ground communication. Hyperloop communication network eventually inherits the general structure of the conventional HSR networks, but with some adjustments to fulfill the specific requirements of Hyperloop. The tube surrounding the train may block any upcoming signal, so the network must consider the need to establish a reliable communication between the pod and the outside world. The general architecture of Hyperloop communication network is shown in Fig 1.

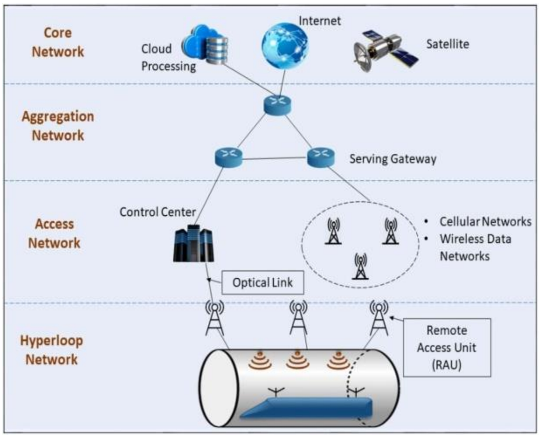

Fig 1: Network architecture of hyperloop communication

A. *Core network:* The core or backbone network is the part that binds and interconnects different participants of the network, providing low congestion, short delays, high availability and adaptability to future applications. In HSR systems, data and services processing is performed at the core network level, with handover processing executed through the mobility management entity (MME) in LTE networks.

B. *Aggregation:* The aggregation network is responsible for gathering, organizing, and forwarding data flows between access and backbone networks. It is composed of the packet data network (PDN) and serving gate-way (SGW). Technologies such as ADSL, IEEE 802.11, Ethernet and optical fibers can be used.

C. *Access network:* the access network is the frontline of the network and is responsible for transmission and reception of signals, coding/decoding, modulation/demodulation. It can be executed in one unit or distributed among units depending on the technology used.

D. *Hyperloop network:* Hyperloop is composed of a tube and a traveling pod, and the inner network is different from conventional HSR systems. Communication between the access network and the tube can be wireless or wired. Antennas are placed on the ceiling of the tube and communicate with one or two antennas placed on top of the pod. Signals from the train control unit and passengers are received by the TAT inside the pod to avoid attenuation.

V. Research Direction For Hyperloop Communication

A. *Antenna-Based solutions*: Antennas are essential for Hyperloop communication, as they represent the interface between the wave propagating through the air and the electrical signal carrying information. Challenges include large bandwidth, radiation efficiency, directivity, array size, and Doppler effect mitigation. Leaky waveguides, also known as slotted antennas, are commonly used in Hyperloop communication systems to suppress Doppler shift. Helical distribution was adopted as the fundamental concept, and novel structures were proposed to reduce the impact of Doppler shift on system performance. Two structures were proposed to avoid penetration loss when the UE inside the pod communicates with the leaky waveguides.

B. *Network-Based solutions:* Network-based solutions can mitigate the handover challenge of Hyperloop communication, such as connecting all passengers to a relay BS inside the pod and using distributed antenna systems (DAS) and cloud radio access networks (CRANs). CRAN architecture centralizes computational tasks in a shared pool, promoting efficient resource sharing and energy-saving, making services faster and more flexible. CRAN architecture reduces handover delay to 5 ns, and 5G network architecture uses eNodeBs and OWC to increase reliability.

C. *Radio-Based solutions:* The moving cell approach is a widely adopted technique to reduce handovers in HSR systems. It allows the BS to connect to successive RAUs using the same radio frequency and optical switching to replace the handover at each RAU boundary. The moving cell approach is the core technology of the sliding window method and provides insights into resource allocation and performance analysis.

D. *Software-Based solutions:* A comprehensive software solution is needed to ensure the smooth operation of the Hyperloop system. Wireless sensors networks are used to track parameters and transmit data to the control system, while the driver can access the user interface to control the pod and communicate with other drivers and agents. Results showed that the system was capable of executing control commands, gathering distributed data from sensors and accurately evaluating the launch performance.

VI. Advantages

- *High-speed communication:* if the wireless system were designed to be compatible with the high speeds of the hyperloop transportation system, it could potentially provide fast and reliable communication for passengers and other stakeholders.
- *Enhanced coordination and control:* A communication system could be used to provide real-time monitoring and communication between the hyperloop vehicle and control center, which could enhance safety and prevent accidents.
- *Improved communication infrastructure:* The construction of the hyperloop system could potentially involve the installation of communication infrastructure, such as fiber optic cables, that could improve communication capabilities in the areas where the system is built.
- *Increased connectivity:* The hyperloop system could potentially connect previous disconnected communities, allowing for improved communication and collaboration between regions.
- *Reduced travel times:* By reducing travel times between cities, the hyperloop system could potentially enable more efficient communication and collaboration between businesses, governments and individuals.

VII. Future Scope

- *Service requirements:* Hyperloop requires strict service requirements in terms of delays, transmission errors, and data rates. To meet these requirements, a system must be designed that can reach 1 ms and 106, respectively. Millimeter, THz, and optical waves are suitable candidates, but they suffer high atmospheric absorption and scattering. MIMO and massive MIMO are interesting techniques to investigate. FSO can be deployed inside the vacuum tube, but it is inherently secure and has a high reuse factor. Steering the light beam is necessary, but this setup may increase the overall cost of the system.
- *Channels models:* The most important idea is that reliable statistical channel models must be developed and confirmed through measurements and real-world system experiments to allow accurate future systems designs. Data must be collected and stored in databases to reduce computational complexity.
- *Handover and Doppler effect mitigation:* Hyperloop sonic speed has caused frequent handover and severe Doppler shifts. To address these issues, fast handover algorithms and techniques such as Doppler diversity and intelligent reflecting surfaces (IRS) can be used. Non-coherent differential spatial modulation (SM) can also be used to mitigate Doppler shifts, bypassing channel state information estimation.

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VIII. CONCLUSION

The difficulties posed by the Hyperloop communication system are very different compared to those seen in traditional HSR systems, leading to communication problems and events that the HSR communication community is unaware with. The challenge of creating a full and effective communication system is exceedingly difficult due to the unique architecture of the train, extremely high speed requirements, and the current amenities that passengers expect.

This paper provides a thorough analysis of the Hyperloop communication system as well as many research projects carried out to solve various problems and suggest viable solutions that could effectively support Hyperloop. Recent studies have produced a number of options, from antenna design and network topologies to radio systems, that can successfully handle the unique structure of the Hyperloop. While examining the near and far fields of the antenna, leaky waveguide antenna designs are usually suggested to minimise the Doppler shift. To further reduce the number of executed handovers, radio systems that use the moving cell concept have been investigated. The adoption of a centralised design in conjunction with optical fibres was thought to reduce handover delay in network architectures like DAS and CRAN.

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