Towards Smart Transportation: The Synergy of Space Shift Keying and Reconfigurable Intelligent Surfaces for Future V2V Networks.

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Abstract.

In search of smarter and more efficient transportation networks, the integration of Space Shift Keying (SSK) and Reconfigurable Intelligent Surfaces (RIS) for future Vehicular-to-Vehicular (V2V) networks is analysed. With 28 GHz mm-wave (FR2 n261 Band), the proposed scheme utilizes SSK's distinguishing feature in terms of efficient use of energy and RIS for assured delivery of signals. Performance investigation is conducted over key performance factors such as Bit Error Rate (BER), Received Signal Strength Indicator (RSSI), Reference Signal Received Power (RSRP), path loss analysis in NLoS and LoS scenarios, and Channel Impulse Response (CIR) analysis. In identifying the potential of RIS to compensate for path loss and improve signal quality even in poor (Rain-faded weather) propagation scenarios, SSK and RIS viability for supporting reliable 5G-based V2V communications is shown in this work. In providing a platform for developing future V2V networks towards smart and connected transportation networks, this work paves avenues for future development and enhancements in vehicular networks for efficient and reliable communications in smart and connected transportation networks.

Keywords. RIS, SSK, MIMO, Rician channel, CI model.

1. Introduction

Ongoing research in V2V communication focuses on various aspects, including performance evaluation and the integration of emerging technologies such as Reconfigurable Intelligent Surfaces (RIS). These technologies will improve connectivity and safety in vehicular networks, and this will lead to completely automated traffic management systems [1]. RIS technology allows control of the wireless signal propagation channels, which consequently results in signal power enhancement and overall communication efficiency [2]. By controlling the reflection of radio waves, RIS can create secure communication channels that are only available to legitimate vehicles, thus reducing the dangers of eavesdropping and spoofing attacks [3].

Space Shift Keying (SSK) is a recently introduced digital modulation technique that finds its major applications in wireless communication systems, specifically in Multiple-Input Multiple-Output (MIMO) channels. SSK is a notable contribution to the vast area of Spatial Modulation (SM) techniques. The concept of SSK is to convey information through the activation of some antennas on the transmitter side; the data symbol is conveyed by the index of the active antenna, hence differing from the traditional modulation schemes that employ the change in the carrier signal [4][5].

The receiver de-multiplexes the information transmitted based on the detection of the active antenna, thus mitigating inter-channel interference and minimizing receiver implementation complexity. Lower receiver design complexity is one of the main advantages of Shifted Signal Keying (SSK). This characteristic makes it extremely desirable to applications where receiver complexity reduction is desirable, e.g., in sensor networks and the Internet of Things (IoT) [4][6].

SSK benefits automatically from spatial diversity because it uses more than a single antenna. Spatial diversity can reverse fading effects and improve the channel robustness [5]. SSK can also fight certain types of interference effectively by utilizing the spatial variation of the signal to enable stable transmission of data even in adverse conditions [6].

2. System and Channel Model:

The combination of Spatial Shift Keying (SSK) and Reconfigurable Intelligent Surfaces (RIS) is of enormous potential to revolutionize vehicular communication systems. For instance, RIS can resolve issues like signal obstructions, interference, and path attenuation by sending reflected signals directly to the moving vehicles even in the case of changing environments. This combination is especially helpful in urban environments with obstructions or highways where vehicles are traveling at high speeds. Additionally, both SSK and RIS are low-power consumption technologies, which are ideal for future vehicular networks emphasizing sustainability and scalability without compromising performance.

In vehicular networks, the whole channel consists of three components: the direct link between the vehicle and the transmitter, the transmitter-RIS link, and the RIS-vehicle link. The direct link is prone to severe fading and building, vehicle, or other obstacles' blockage. The RIS-assisted link, on the other hand, has the benefit of the surface to dynamically adjust to changing conditions to enhance the signal strength and reliability. The RIS-vehicle interaction is the most difficult due to the mobility of the vehicles, leading to Doppler shifts and rapidly changing channel conditions. To overcome these difficulties successfully, the channel model needs to include aspects of path loss, small-scale fading—grounded in Rayleigh or Rician fading—as well as Doppler-induced phase oscillations. Environmental factors, such as rain, also impair the signal, and the RIS needs to continuously adjust its phases accordingly to provide uniform communication. With the deployment of this wide-spectrum channel model, SSK-RIS systems can significantly improve signal reliability, efficiency, and robustness, which in turn translates into more secure and reliable vehicular communication networks.

Path Loss (CI Model): $$PL(d_{rr,k,m}) = PL_0 + 10.n.log_{10}\left(\frac{d_{rr,k,m}}{d_0}\right) \quad (1)$$

Channel coefficient(Rician Model):

$$h_{rr,k,m}(t) = \sqrt{\frac{K}{K+1}}\, h_{LOS,k,m}(t) + \sqrt{\frac{1}{K+1}}\, h_{NLOS,k,m}(t) \quad (2)$$

LOS Component: $$h_{LOS,k,m}(t) = a_{rr,k,m}(t).e^{j(2\pi f_{D,m}t+\phi_{rr,k,m})} \quad (3)$$

NLOS Component: $$h_{NLOS,k,m}(t) = X_{k,m} + jY_{k,m} \quad (4)$$

The received signal $y_k(t)$ at the k^{th} receiver antenna becomes

$$y_k(t) = \underbrace{\sqrt{P}h_{d,s,k}(t)}_{Direct\ Link} + \underbrace{\sqrt{P}\sum_{m=1}^{M} h_{rr,k,m}(t)\,.\,e^{j\phi_m}.\,h_{tr,s,m}(t)}_{RIS\ Assisted\ Link\ with\ Rain\ Fading} + n_k(t) \quad (5)$$

Expanding the RIS-assisted link term,

$$\sum_{m=1}^{M} h_{rr,k,m}(t)\,.\,e^{j\phi_m}.\,h_{tr,s,m}(t) = \sum_{m=1}^{M}\left[\sqrt{\frac{K}{K+1}}a_{rr,k,m}(t).\,e^{\frac{-A_r}{20}}.\,e^{j(2\pi f_{D,m}t+\phi_{rr,k,m})} + \sqrt{\frac{1}{K+1}}h_{NLOS,k,m}(t)\right].\,e^{j\phi_m}.\,h_{tr,s,m}(t) \quad (6)$$

where,

$a_{rr,k,m}(t)$ is the time-varying amplitude due to path loss, computed using the CI model. $f_{D,m}$=$\lambda v cos(\theta_m)$is the Doppler shift for the m^{th} RIS element. $\phi_{rr,k,m}$ is the initial phase offset $h_{d,s,k}(t)$ is the direct link channel coefficient, also modeled using the CI and Rician models. $h_{rr,k,m}(t)$ is the RIS-to-vehicle channel coefficient, incorporating both LOS and NLOS components as described above $h_{tr,s,m}(t)$ is the static transmitter-to-RIS channel coefficient

3. Simulation Results:

This paper analyses SSK-based RIS for V2V communication in detail. The performance evaluations are targeted at aspects such as BER vs. SNR, RSSI vs. distance, and path loss due to extreme weather conditions such as heavy rain and fog, as well as large and small fading effects considering CI and Rician fading models, respectively, adding Doppler shifts and NLoS/LoS channel errors to account for real-world vehicular communications. SSK with RIS takes advantage of spatial diversity and better energy efficiency; thus, it is expected to be a better choice in vehicular networks. This research advances to demonstrate how SSK-RIS-based V2V architectures are used to mitigate signal degradation and improve coverage, particularly in harsh environments, for 28GHz communications. The results indicate that the combination of SSK with RIS improves communications' reliability, thus promising the use of this approach for robust and efficient V2V connectivity.

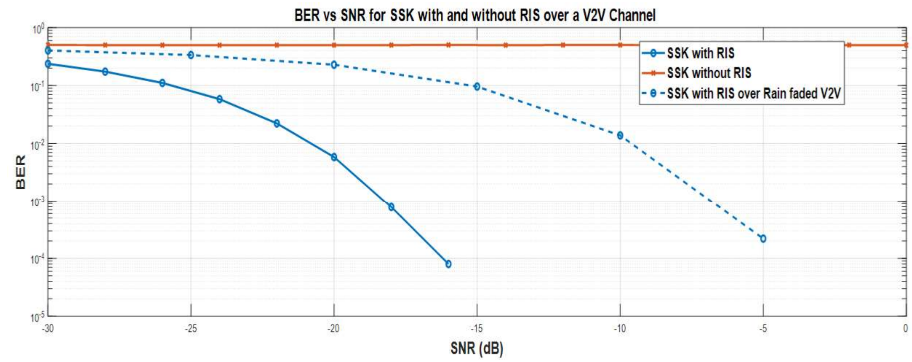

Fig:1 BER vs SNR Comparison for SSK with and without RIS over a V2V Channel

Fig.1 depicts the performance of BER with respect to SNR for SSK at 28GHz under three conditions of using RIS, without RIS, and with RIS under rain-faded V2V channels. The major advantage in BER attributed to the presence of RIS is visible in the plot as against the case of without RIS. The impact of rain fading is observed as the performance gets degraded when compared to that of a clear V2V channel with RIS. These results indicate how effectively RIS can enhance the system's reliability even under very poor conditions.

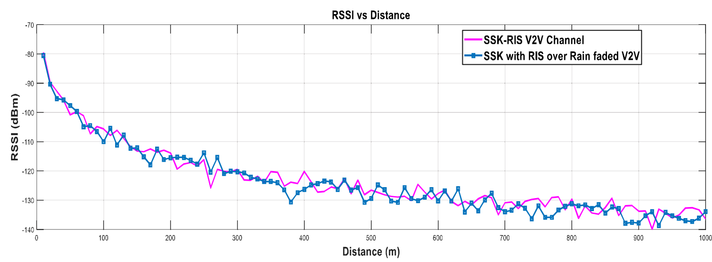

Fig: 2 RSSI vs Distance Comparison for SSK with RIS over a V2V Channel and Rain-Faded Effect.

Fig.2 shows RSSI vs distance of travel from the base station. Whenever the RSSI goes below -130 dBm the signal gets degraded, and the link is said to be broken. Similarly, if we carefully observe the 2 plots, SSK with rain fading has degraded performance because of the rain attenuation, and the intensity of the rain is set up to 25mm/hr, which is moderate to heavy rain attenuation. We observe that, at a distance of 380m away from the BS, SSK-RIS over rain-faded channel experiences link breakdowns, whereas the normal SSK-RIS in no rain environment experiences the same link breakdown at a distance of 620m from the BS. Similar trends are observed in Fig.3, where the Reference signal Received power vs distance shows the 480-meter distance a vehicle could cover before the signal drops below -130dBm in a rain faded scenario, in comparison to no rain it is approximately 680m distance. Fig.4 demonstrates the Path loss vs distance within the cell. It is observed that higher path loss is observed in NLoS faded SSK-RIS system in comparison to the LoS faded SSK-RIS system, this is because rain fading in an NLoS scenario increases the path loss as compared to LoS path loss as given in equation (5). Finally, in Fig. 5, Channel Impulse response has been plotted for SSK-RIS and SSK system under a typical V2V scenario, and it is observed that the magnitude of the SSK-RIS system has very high magnitudes (higher peaks indicates larger reflections and better performance) even in rain-affected scenarios which helps in decoding the signal better than its counterparts.

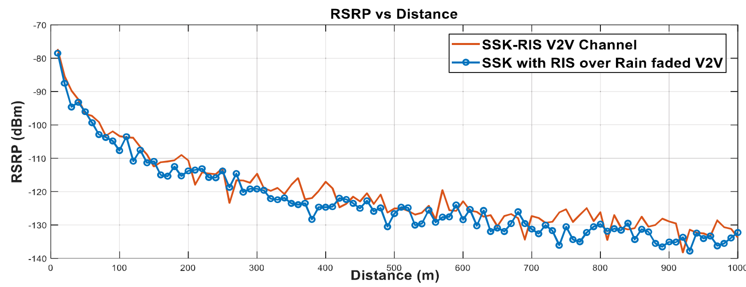

Fig:3 RSRP vs Distance for SSK with RIS over a V2V Channel

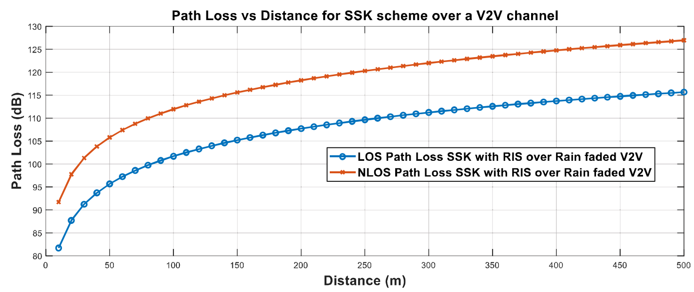

Fig:4 Path loss vs Distance for SSK with RIS over a V2V Channel and Rain Faded Effect

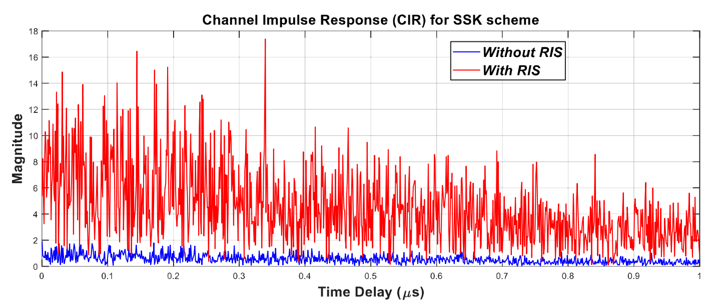

Fig :5 Channel Impulse Response with and without RIS.

4. CONCLUSIONS AND FUTURE WORK.

On a concluding note, RIS-SSK integrated into a V2V environment can effectively enhance the reliability as well as efficiency of communication. Performance measures such as BER, RSSI, and RSRP, in addition to path loss analysis in both LoS and NLoS scenarios, show that the system effectively increases the strength of the signals, reduces their error rates, and is robust against several impairments in the channel. Also, CIR is incorporated to demonstrate how the system can adjust within a dynamic environment. Future work would include real-time optimization of phase shifts in RIS by means of well-defined machine-learning techniques to address improving functionality in extremely varying mobile conditions.

5. REFERENCES

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Biography

Suhas K received the bachelor's degree in Electronics & Communication Engineering from VTU Belgaum in 2009, the master's degree in Control Systems from Manipal Academy of Higher Education in 2011 respectively. He is currently working as an Assistant Professor at the Department of Electronics & Communication Engineering, Manipal Institute of Technology, Manipal. His research areas include developing energy efficient modulation schemes for wireless systems, Channel Coding and Error Correction, Millimeter-Wave (mmWave) and Terahertz (THz) Communication.