A High Capacity Hybrid WDM-MDM-Ro-FSO System Using LG00 and HG00 Modes for Broadband Services in Hospitals

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Abstract— **Researchers have been working on next-generation communication systems to meet rising need for high-speed communication as a result of the explosive growth of subscribers each year. Millimetre waves, which operate in the 30 GHz to 300 GHz range, have the potential to be used as a data carrier. However, because to the direct influence on patients' health and severe interference with other medical devices, these radio waves are subjected to rigorous controls in hospital settings, posing a significant challenge to patients. As a result, providing communication/ broadband services for transmission of such sensitive biological sensor data at hospital sites is a difficult for the researchers. Radio over Free Space (Ro-FSO) devices would become an appealing option for delivering millimetre waves via a high-speed free space link. In addition to the wavelength division multiplexing (WDM) scheme, mode division multiplexing (MDM) plays an important role in increasing the capacity of Ro-FSO systems. In this paper, we show how the MDM-WDM system can support four channels, each with a capacity of 10 Gbps, which can be up converted to 40 GHz through an FSO link and used to provide internet and communication services within the hospital. Furthermore, the proposed system is investigated for different modulation formats such as Non return to zero (NRZ), Compressed spectrum RZ (CSRZ) and Duo-binary RZ (DRZ) in various fog circumstances. It is observed that DRZ surpasses the performance of CSRZ and NRZ due to better spectral efficiency and greater tolerance to nonlinear effects and pulse width broadening.**

Index Terms: **WDM, MDM, Ro-FSO, NRZ, CSRZ, DRZ.**

1.INTRODUCTION

Since the previous decade, the need for wireless communication has grown quickly, resulting in the development of optical wireless communication systems. There are four billion users due to 20% rise in the consumers of mobile broadband by 2017 as per the International Telecom Union (ITU) [1]. This heightens the difficulty for the ITU in allocating radio frequency (RF) spectrum to various cellular carriers, both in rural and urban locations [2]. However, due to radio signal interference with sensitive medical instruments and the substantial impact on patients' health, providing broadband services in hospital settings is not always practical [3]. As a result, radio waves are not permitted in medical settings. This prospective use of internet services also poses a significant problem for broadband providers in terms of providing services in hospitals without jeopardising patient health. Ro-FSO enables multiple RF signal transmission without the need for a costly optical fibre infrastructure or a license for RF operators [4]. Ro-FSO also becomes an appealing alternative for offering broadband services in hospitals since data transmission occurs without the interference to the equipments used in hospitals due to the transmission of photonic signals. Furthermore, owing to the necessity for continuous working operations and limited space in hospital locations, a prominent way out is Ro-FSO [5]. It may also exchange RF signals with huge bandwidths and low attenuation and power consumption. FSO, on the other hand, does not employ optical fibres. Instead, it facilitates quick adoption of atmospheric data transfer. In addition, unlike RF broadcasting, it does not require a licence. Ro-FSO is a suitable technology for offering broadband services in hospitals because of the combined qualities of RoF and FSO. As a result, Ro-FSO is a useful technology for integrating RF wireless networks in a smooth, quick, and cost-effective manner [6]. However, air turbulences such as scintillations, fog, rain, snow, and other factors impact the signal-to-noise ratio of Ro-

FSO [7] [8]. As a result of the increased attenuation in the transmission line, the network is forced to shut down. As a result, when developing the Ro-FSO network, researchers should take these turbulences into account. MDM, or mode division multiplexing, is another new technology that delivers data over several channels using different modes [9].In 2018, directly modulated Ro-FSO system for 3.6 m is demonstrated in [10] using 64 QAM. An orthogonal frequency division multiplexing (OFDM) Ro-FSO system for 30 km with the incorporation of mode division multiplexing (MDM) and spectrum slicing is reported in [11]. Further, a MDM and WDM-RoFSO system is proposed over 2000 m under heavy fog conditions [12]. Gamma-Gamma FSO model is investigated using K-phase shift keying and OFDM user weak, moderate, and strong scintillations [13]. Combining MDM and WDM in Ro-FSO infrastructures can enhance aggregate capacity and improve spectral efficiency, which can be useful in hospital infrastructures. Further, modulation formats have great impact on the performance of the FSO systems due to their spectral efficiency, tolerance to dispersion, nonlinear effects, and noises [14]. Therefore, in this work, different NRZ, CSRZ and DRZ are investigated in 4×10 Gbps WDM-MDM-Ro-FSO system for application in hospitals under different fog conditions such as clear weather, low fog, medium fog, and heavy fog.

Section 1 covers the introduction about WDM, MDM, Ro-FSO, and literature of Ro-FSO systems. Proposed system setup is discussed in Section 2 with simulation parameters and results of the different modulation are presented in Section 3. Finally conclusion is drawn in Section 4.

2. SYSTEM SETUP

Figure 1 represents the proposed 4×10 Gbps Ro-FSO system using MDM under clear weather, low fog, medium fog, and heavy fog. The hybrid WDM-MDM method is used to transmit four channels on three wavelengths such as 850 nm, 851 nm) having channel spacing of 1 nm. MDM modes for channels are LG00 and HG00 such that same wavelength transmits using different modes to double the capacity and to minimize the use of wavelengths. For the up-conversion process, each channel has different modulations such as NRZ, CSRZ and DRZ data of 10 Gbps combined with a 40 GHz millimetre wave created by a sine generator with the assistance of a mixer. With the use of Mach zehnder modulator (MZM), 40 GHz millimeter waves are modulated on optical carriers.

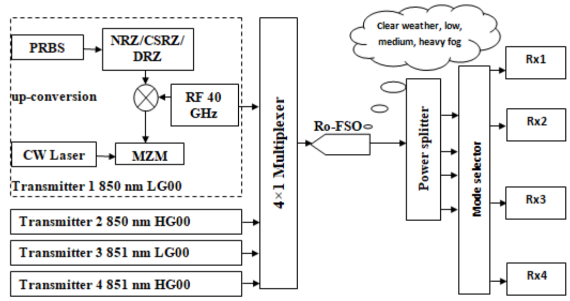


Figure 1 Proposed Ro-FSO system using LG00 and HG00 modes using NRZ/CSRZ/DRZ

Output from the eight transmitter are combined with 8×1 multiplexer and then fed to FSO channel. System specifications are listed in Table 1 which are used to complete the proposed work.

Table 1 Values of different parameters in proposed system

Parameters	Values
Data Rate	10 Gbps
Capacity	8×10 Gbps
MDM modes	LG00, HG00
Modulations	NRZ, CSRZ, DRZ
RF frequency	40 GHz
Wavelengths	850 nm, 851 nm and 852 nm
Input power	0 dB
FSO Transmitter aperture diameter	10 cm
FSO Receiver aperture diameter	20 cm
Beam divergence	2µrad
Photodetector	APD
Gain	3
Dark current	10nA
Thermal noise power spectral density	100e-024 W/Hz

Atmospheric conditions has significant affect on the performance of the FSO and therefore, in this work, different conditions are analyzed such as clear weather, low fog, medium fog, and heavy fog. Values of different atmospheric condition are shown in Table 2 with respective attenuation values.

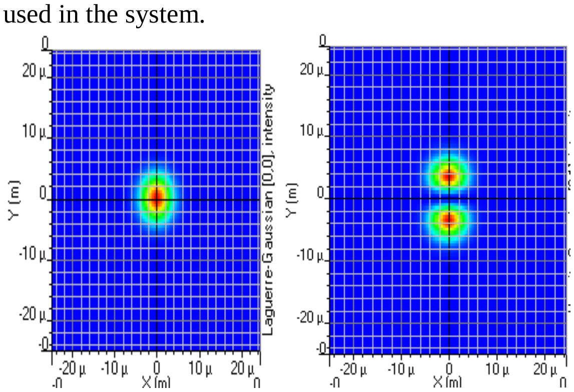
Table 2 Atmospheric conditions and values

Atmospheric condition	Attenuation
Clear weather	0.14 dB/km
Low fog	12 dB/km
Medium fog	16 dB/km
Heavy fog	22 dB/km

After transmission through FSO link, a splitter is placed to separate different wavelengths and followed by mode selectors. Further all the eight signals are made to fall at APD photodetector for the conversion of optical to electrical domain. APD has gain 3, and has shot and thermal noises. To get RF signal back, down-conversion process took place and baseband signal retrieved back with low pass Bessel filter. Final output is observed at eye diagram analyzer in terms of log BER.

3. RESULTS AND DISCUSSIONS

Proposed system is investigated for different distances under the effects of fog conditions and system is analyzed in optiwave optisystem. Figure 2 represents the (a) LG00 and (b) HG00 modes that are used in the system.



(a) (b)

Figure 2 Representation of (a) LG00 mode (b) HG00 mode in spatial analyzer

Figure 3 shows the performance 850 nm for channel 1 and channel 2 under clear weather atmospheric condition using NRZ, CSRZ and DRZ modulation formats in terms of log BER at different link distances. It is observed that both the channel 1 and 2 performed best in case of DRZ due to high spectral efficiency and tolerance to dispersion and nonlinear effects. Performance of DRZ is followed by CSRZ and NRZ is least performing modulation format due to bandwidth inefficient carrier spectrum.

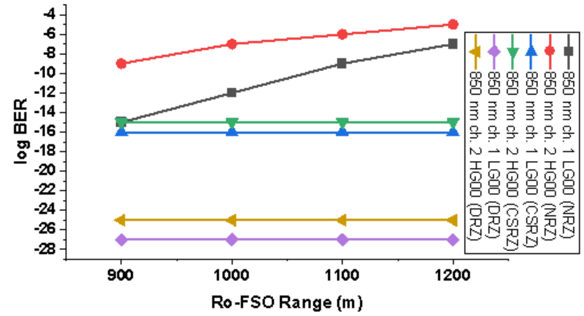


Figure 2 Range versus BER at clear weather (0.14 dB/km attenuation) in case of NRZ, CSRZ and DRZ (Ch. 1 and 2)

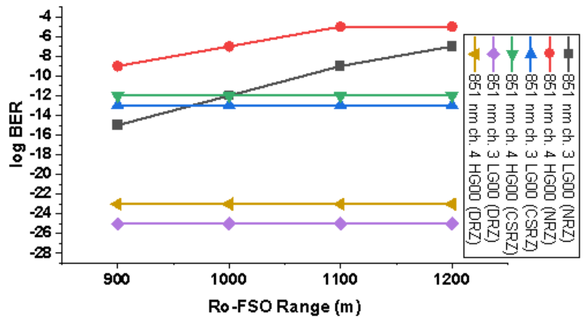


Figure 4 Range versus BER at clear weather (0.14 dB/km attenuation) in case of NRZ, CSRZ and DRZ (Ch. 3 and 4)

Figure 4 depicts the performance 851 nm for channel 3 and channel 4 under clear weather atmospheric condition using NRZ, CSRZ and DRZ modulation formats in terms of log BER at different link distances. Result revealed that both the channel 3 and 4 showed least log BER in case of DRZ and performance of DRZ is followed by CSRZ and NRZ is least performing modulation format.

Figure 4 illustrates the performance of all four channels using NRZ, CSRZ and DRZ modulation formats under the effects of light fog. Light fog has attenuation 12 dB/km and therefore distance covered in this case is lower than the distance covered in clear weather. Total distance is 570 m for low fog and It is perceived that the LG00 in 850 nm using DRZ provide least log BER, followed by performance of HG00 in 850 nm using DRZ, further DRZ LG00 for 851 nm and then HG00 using DRZ for 851 nm. Least performance is offered by NRZ at all four channels.

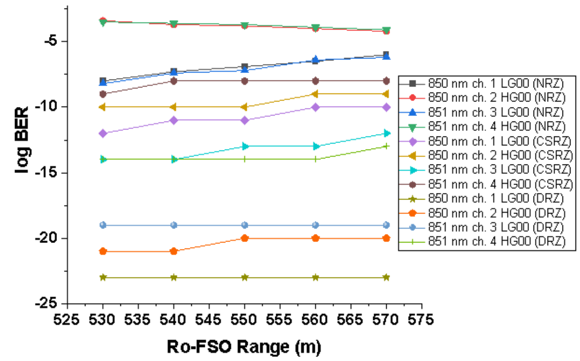


Figure 4 Comparison of NRZ, DRZ and CSRZ in all four channels under low FOG (12 dB/km attenuation)

Further, performance of different modulations is analyzed under medium fog condition in Figure 5. Medium fog has attenuation 16 dB/km and therefore distance covered in this case is lower than the distance covered in low fog. Maximum distance is 510 m for medium fog and It is perceived that the LG00 in 850 nm using DRZ provide least log BER, followed by performance of HG00 in 850 nm using DRZ, further DRZ LG00 for 851 nm and then HG00 using DRZ for 851 nm. Least performance is offered by NRZ at HG00 for 850 nm channel 2.

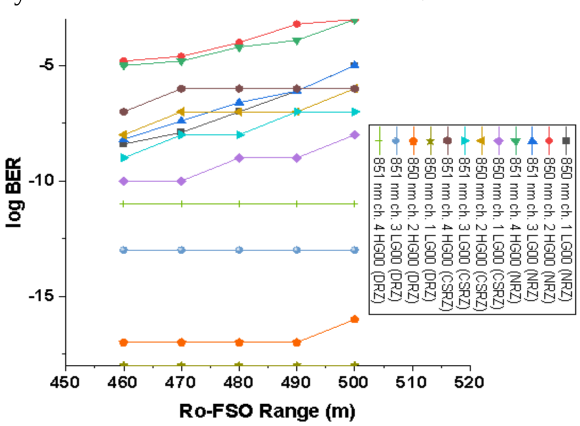


Figure 5 Comparison of NRZ, CSRZ and DRZ in all four channels under Medium FOG (16 dB/km attenuation)

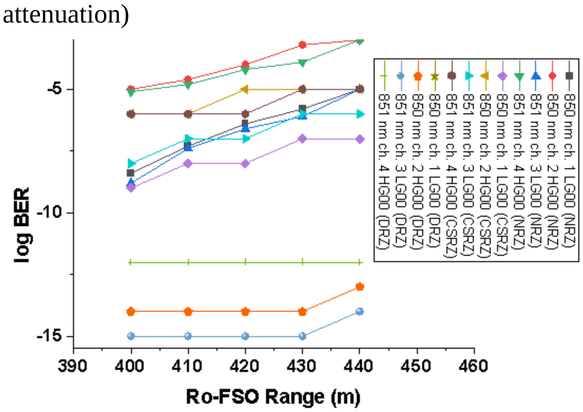


Figure 6 Comparison of NRZ and CSRZ in all four channels under Heavy FOG (22 dB/km attenuation)

Lastly, performance of different modulations is analyzed under heavy fog condition in Figure 6. Heavy fog has attenuation 22 dB/km and therefore distance covered in this case is lower than the distance covered in medium fog. Maximum distance is 440 m for heavy fog and It is perceived that the LG00 in 851 nm using DRZ provide least log BER, followed by performance of HG00 in 850 nm using DRZ, HG00 using DRZ for 851 nm. Least performance is offered by NRZ at HG00 for 850 nm channel 2.

Eye diagrams for CSRZ, and DRZ at 1200 m under clear weather are illustrated in Figure 7 for LG00 and HG00 respectively. Eye diagram represents Q factor, log BER, eye height etc and Maximum eye opening is seen in case of DRZ for LG00 mode followed by HG00 mode.

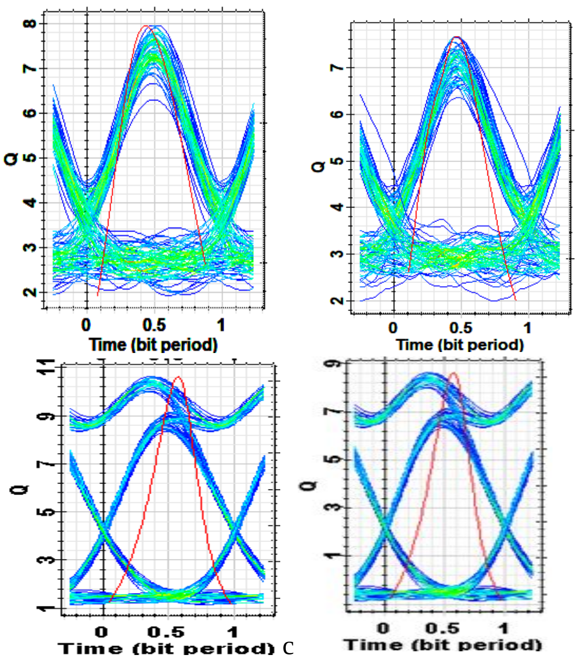
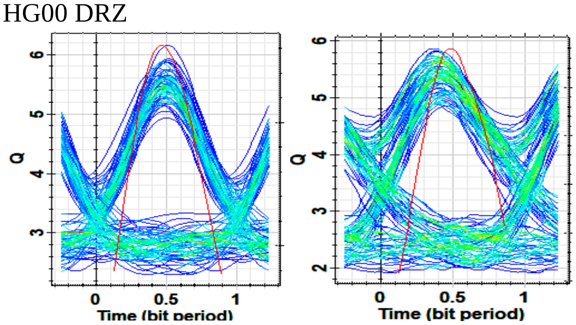


Figure 7 Eye diagram at 1200 m under clear weather (a) LG00 CSRZ (b) HG00 CSRZ (c) LG00 DRZ (b) HG00 DRZ



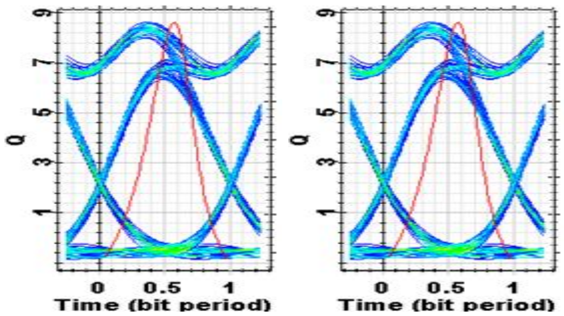


Figure 8 Eye diagram at 540 m for low Fog (a) LG00 CSRZ (b) HG00 CSRZ (c) LG00 DRZ (b) HG00 DRZ

Eye diagrams in case of low fog is further reduced to 540 m due to 12 dB/km attenuation. Eye height also decreases for LG00 and HG00 modes for CSRZ, and DRZ as illustrated in Figure 8. Maximum eye opening is seen in case of DRZ for LG00 mode followed by HG00 mode. LG00 in CSRZ has Q factor 6.2 and for HG00, it is 5.8. In case of DRZ having LG00, Q factor is 8.85 and for HG00, it is 8.84.

Figure 9 depicts the eye diagrams for 440 m in case of medium fog for CSRZ and DRZ having LG00 and HG00 modes.Q factor for LG00 with CSRZ is 5.5, for HG00 with CSRZ is 4.8. For both HG00 and LG00 modes in DRZ has same Q factor value i.e. 7.65.

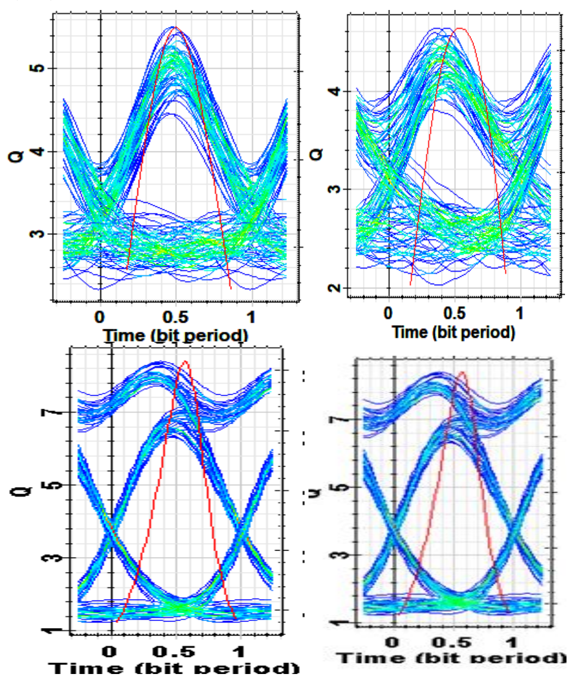


Figure 9 Eye diagram at 440 m medium FOG (a) LG00 CSRZ (b) HG00 CSRZ (c) LG00 DRZ (b) HG00 DRZ

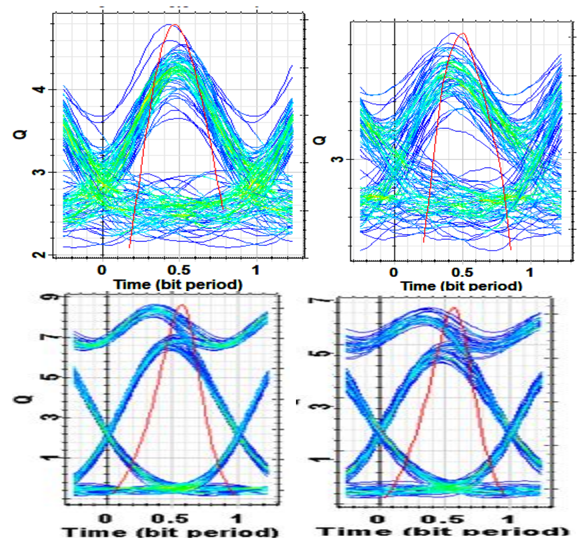


Figure 10 Eye diagram at 400 m heavy FOG (a) LG00 CSRZ (b) HG00 CSRZ (c) LG00 DRZ (b) HG00 DRZ

Figure 10shows the eye diagrams for 400 m in case of heavy fog for CSRZ and DRZ having LG00 and HG00 modes. Q factor for LG00 with CSRZ is 4.8, for HG00 with CSRZ is 3.9. For LG00 and HG00 modes in DRZ has Q factor value 8.6 and 6.6 respectively.

Further, a comparison between reported work and proposed work is performed and shown in Table 3. It is worth to note that proposed DRZ Ro-FSO system with MDM performed best out of CSRZ and NRZ.

Table 3 Comparison of reported work and proposed work

Parameter	Existing work [14]	Proposed Work	Improvement
Data rate	10 Gbps	10 Gbps	-
WDM Channels and wavelengths	2 and 850 nm, 851 nm	2 and 850 nm, 851 nm	-
Mode Used	LG00 and HG00	LG00 and HG00	-
Modulation format used	NRZ	CSRZ, DRZ	-
BER (Clear weather)	1200 m @10^{-7} LG00, 10^{-5} HG00	1200 m @10^{-16} LG00, 10^{-15} HG00 for CSRZ and @10^{-27} LG00, 10^{-25} HG00 for DRZ	128.57% LG00, 200% HG00 CSRZ and 285.71% LG00, 400% HG00 DRZ
BER (Low FOG)	570 m @10^{-6} LG00, $10^{-4.2}$ HG00	570 m @10^{-10} LG00, 10^{-9} HG00 CSRZ and	66.66% LG00, 114.28% HG00 CSRZ and 283.33% LG00, 400% HG00

		@10^{-23} LG00, 10^{-21} HG00 for DRZ	DRZ
BER (Medium FOG)	500 m @10^{-5} LG00, 10^{-3} HG00	500 m @10^{-8} LG00, 10^{-6} HG00 CSRZ and @10^{-18} LG00, 10^{-16} HG00 for DRZ	60% LG00, 100% HG00 CSRZ and 260% LG00, 433% HG00 DRZ
BER (Heavy FOG)	440 m @ 10^{-5} LG00, 10^{-3} HG00	440 m @ 10^{-7} LG00, 10^{-5} HG00 CSRZ and @10^{-21} LG00, 10^{-14} HG00 for DRZ	40% LG00, 66.66% HG00 CSRZ and 320% LG00, 366% HG00 DRZ
Maximum distance covered	1200 m @ clear weather, 570 m @ low fog, 500 m @medium fog, and 440 @heavy fog	1500 m @ clear weather, 590 m @ low fog, 525 m @medium fog, and 480 @heavy fog	25% clear weather, 3.50% low fog, 5% medium fog, 9.09% heavy fog

4. CONCLUSION

In this work, a MDM-WDM system is demonstrated for hospitals supporting Ro-FSO with four channels, each with a speed of 10 Gbps. Over a Ro-FSO link, each channel are up-converted to 40 GHz millimeter wave. LG 00 and HG 00 modes are incorporated in MDM, whereas 850 and 851 nm wavelengths are employed in WDM. Furthermore, the proposed system is investigated for different modulation formats such as NRZ, CSRZ and DRZ in various fog circumstances. It is observed that DRZ surpasses the performance of CSRZ and NRZ due to better spectral efficiency and greater tolerance to nonlinear effects and pulse width broadening.Distance covered by NRZ is 1200 m in clear weather, 570 m in low, 500 in medium and 440 m in heavy fog. It is observed that DRZ provide distance improvement of 25% (1500 m) in clear weather, 3.50% in low fog (590 m), 5% in medium fog (525 m), and 9.09% in heavy fog (480 m).

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