Towards broadband connectivity for intelligent transport systems and passengers

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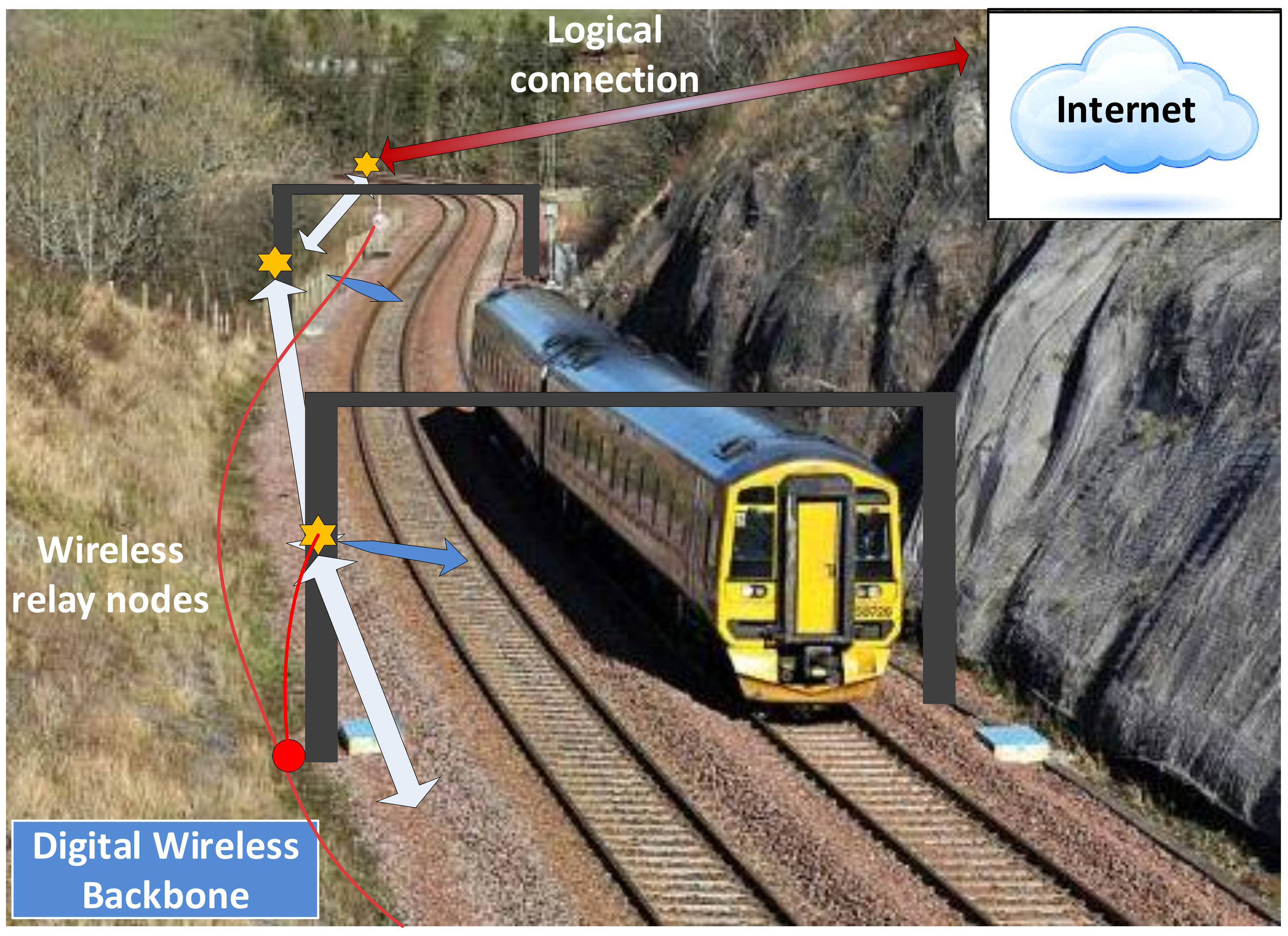
Background

There are 1.69 billion passenger journeys in the UK a year, with an average of 57 minutes per journey[1]. With continued increase in usage of smartphones and tablets with Wi-Fi capability, current systems in place to provide the required Wi-Fi connectivity on trains are not sufficient. One possible solution is a transport connectivity system using radio relays along the trackside, and this is analysed below.

Wireless backbone



The proposed system may be able to compliment fibre-optic transmission with a wireless backbone for connecting vehicles, staff and passengers.

A link budget analysis has been performed to ascertain the feasibility of the scheme under various scenarios. Several configurations have been analysed:

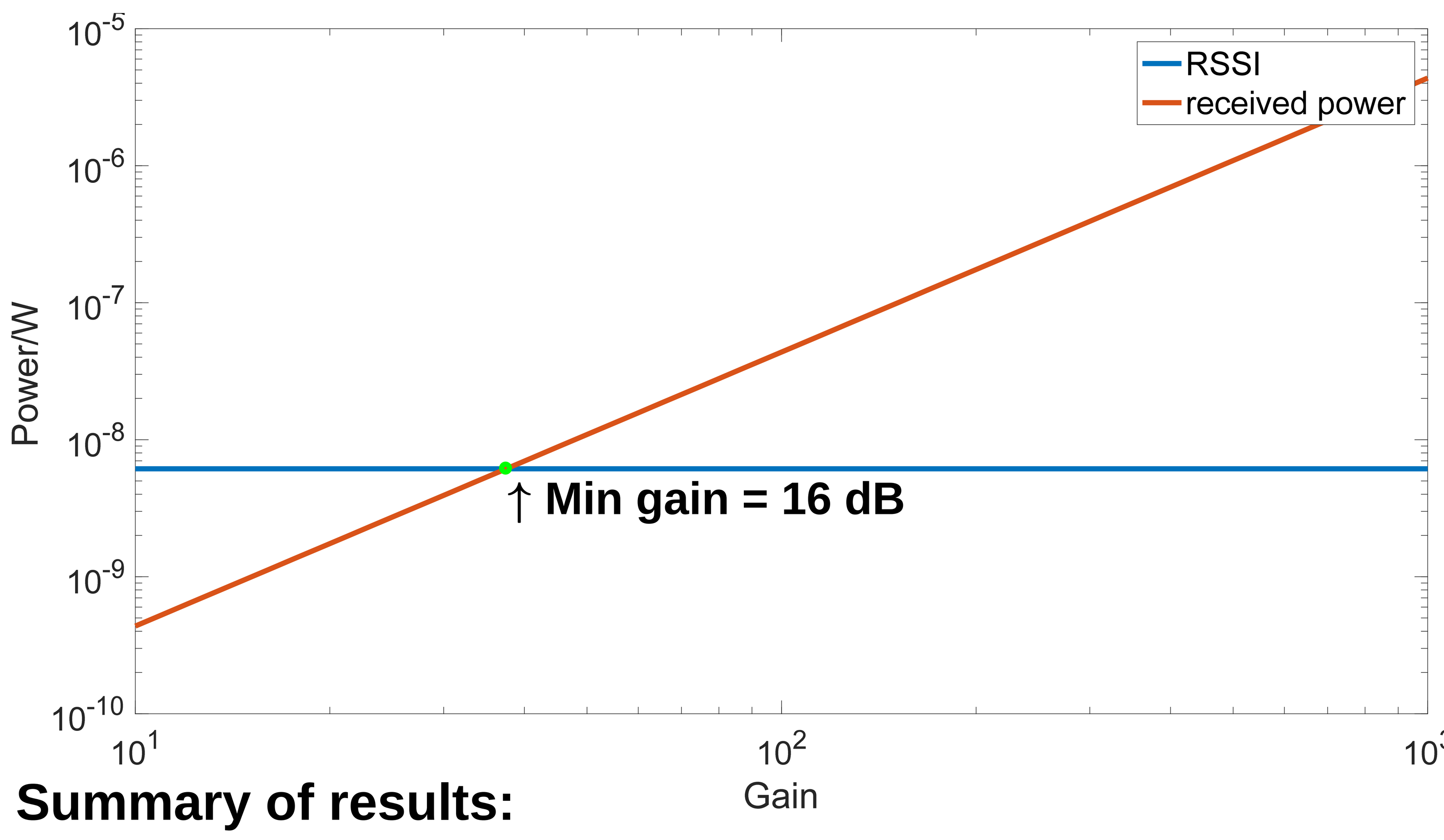
- 2 GHz (4G)
- 5 GHz (IEEE 802.22ac)
- 26 GHz (5G pioneer band #1)
- 60 GHz (5G pioneer band #2).

Example link budget analysis

Assumptions:

- Carrier frequency 26 GHz
- Transmit power 23 dBm
- Minimum receive power required -40 dBm
- Receiver noise figure 9 dB
- Receiver bandwidth 160 MHz
- Data rate of 5 Gbps
- Line of sight signal path along each relay hop.

The graph below shows that for a 26 GHz carrier frequency, signal bandwidth of 600 MHz and data rate of 5 Gbps, an antenna gain of at least 16 dBi is required at both the transmitter and receiver and for each relay.

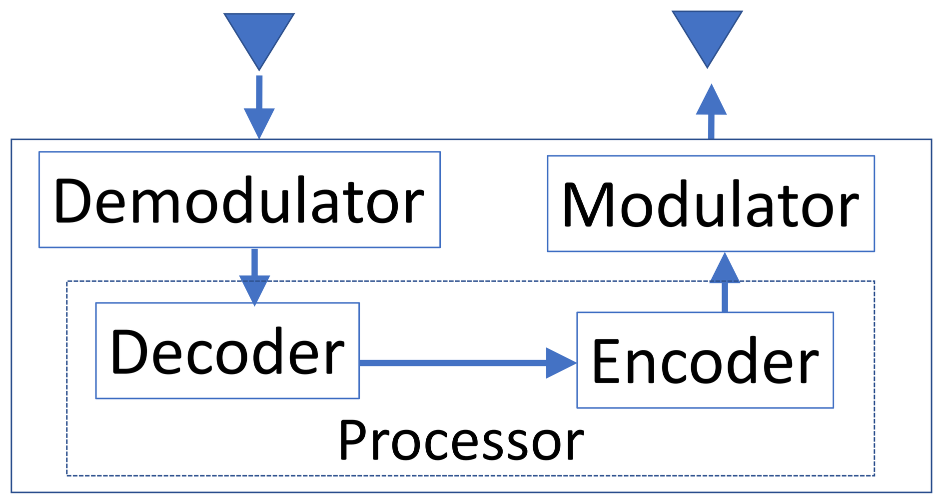


Summary of results:

- 26 GHz requires antenna gains of 16 dBi
- 60 GHz requires antenna gains of 38 dBi due to higher path loss.

prefer 26 GHz due simpler antennas and easier link alignment.

Decode and forward (DF) relay network analysis



Block Diagram of a DF Relay node

The wireless backbone is modelled as a n-hop Decode-and-Forward (DF) relay chain. Analytical solutions for the upper bound of the Bit-Error-Rate (BER) for a given Signal-to-Noise Ratio (SNR) are derived for two modulation schemes: QPSK and BPSK.

A Markov chain is used for the analysis, which describes the probability of a transition of a data bit, i.e. for QPSK modulation:

$$\begin{pmatrix} 1-2P1-P2 & P1 & P1 & P2 \\ P1 & 1-2P1-P2 & P2 & P1 \\ P1 & P2 & 1-2P1-P2 & P1 \\ P2 & P1 & P1 & 1-2P1-P2 \end{pmatrix}$$

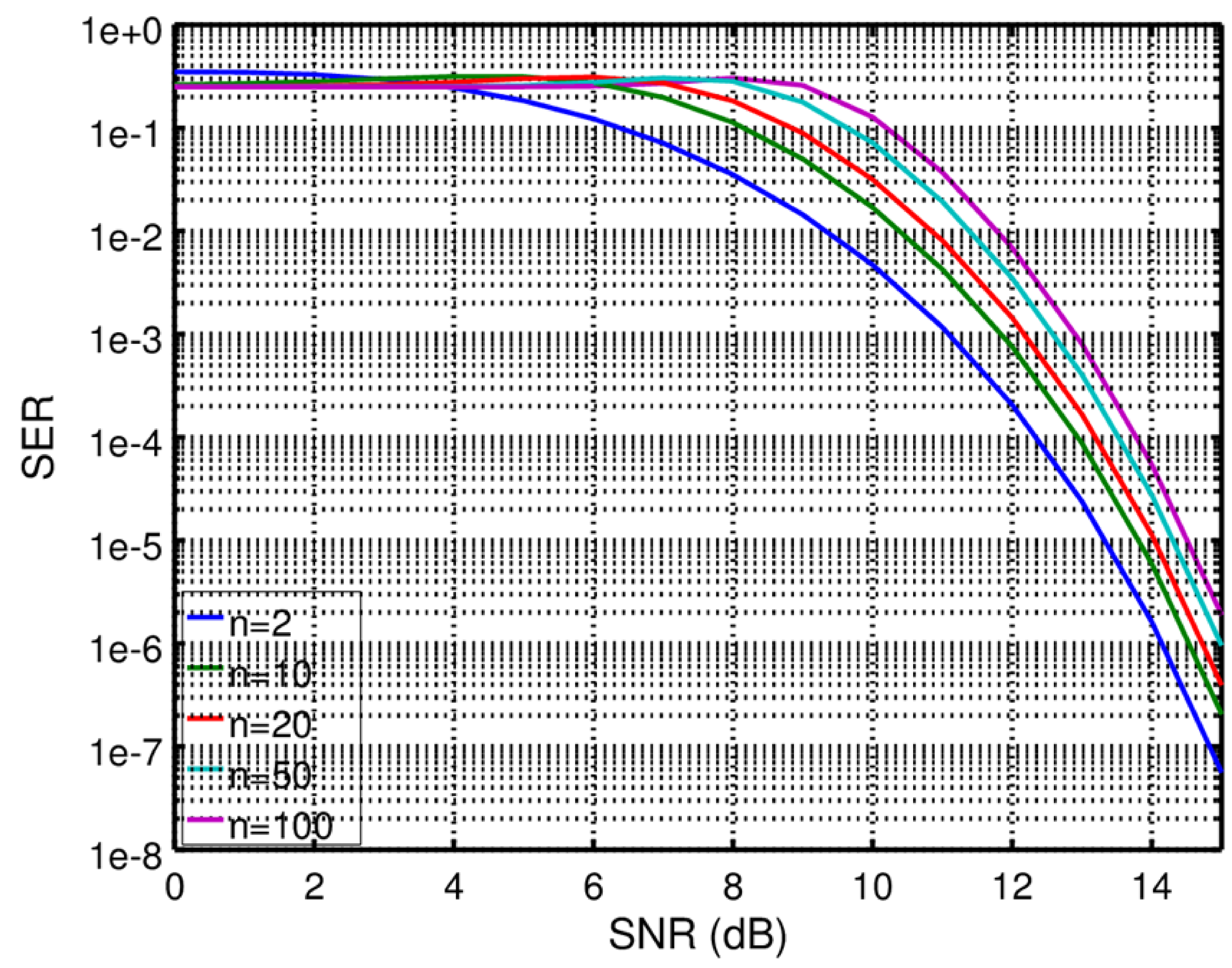
The derivation gives: $P_c = \frac{1}{4} + \frac{1}{4}(1-4P_1)^n + \frac{1}{2}(1-2P_1-2P_2)^n$

Where $P_1 = \frac{1}{2}Q\left(\sqrt{\frac{SNR}{2}}\right)\left(1-Q\left(\sqrt{\frac{SNR}{2}}\right)\right)$, and

$$P_2 = 1 - Q\left(\sqrt{\frac{SNR}{2}}\right)\left(1-Q\left(\sqrt{\frac{SNR}{2}}\right)\right) - Q(\sqrt{SNR}) - \left(2 - Q(\sqrt{SNR})\right)$$

Where Q is the Q-function, SNR is Signal-to-Noise Ratio, *n* is number of hops and BER = 1 - Pc

Analytical results are shown opposite for QPSK Symbol Error Rate and 2, 10, 20, 50, 100 hops.



Conclusions and further research

- Use of the 26 GHz 5G pioneer band for transport and passenger connectivity backbone looks promising
- Use of a DF relay chain in the 26 GHz band has potential for providing the required range
- Further research can be carried out to optimise the scheme. Exploiting Orbital Angular Momentum Multiplexing to increase spectral efficiency may be a means of achieving even higher data rates.

References

[1] Office of Rail and Road 2016-2017 Q1 Statistical Release