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Interference avoidance in indoor visible light communications systems

Visible Light Communications

There is consistent demand for higher data rates delivered wirelessly to more internet-connected devices.

Fibre connections mean that improvement in the speed of radio frequency (RF) WiFi connections is slower than the improvement of the wired connections which support them.

The RF spectrum available to WiFi is limited by regulation and is being used more heavily. This is known as 'spectrum crunch'.

RF propagation is unpredictable. Anyone nearby can communicate with a WiFi access point and access points in neighbouring rooms can suffer from interference which limits frequency reuse.

If the bandwidth assigned to WiFi (≈2.1GHz) were represented by the height of this poster (118.9cm) then the visible spectrum (≈400THz) would stretch from Oxford to Calais (220km).

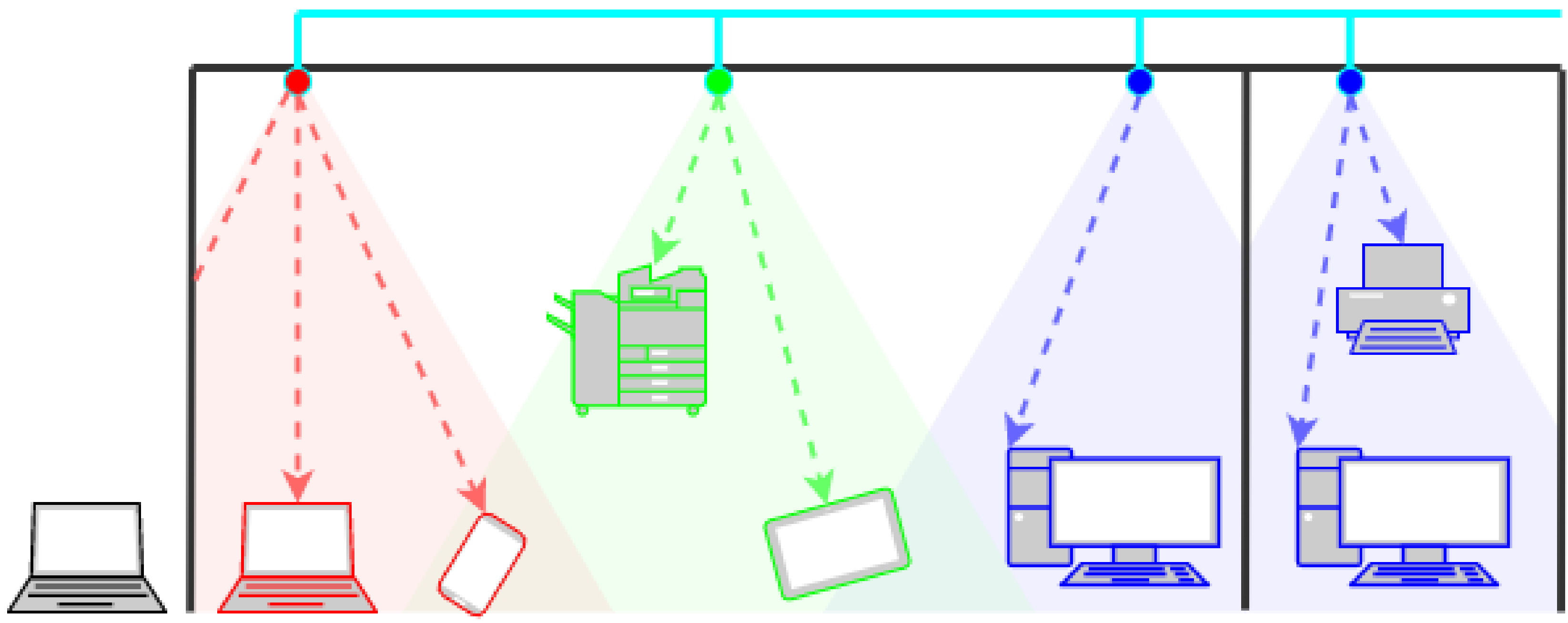
Therefore VLC data rate is limited by hardware (LEDs and photodiodes) rather than spectrum bandwidth. Single links can already achieve more than 1Gbps

Visible light is confined by line of sight, meaning only users in a building can access its network. This increases security and makes interference predictable and mitigatable.

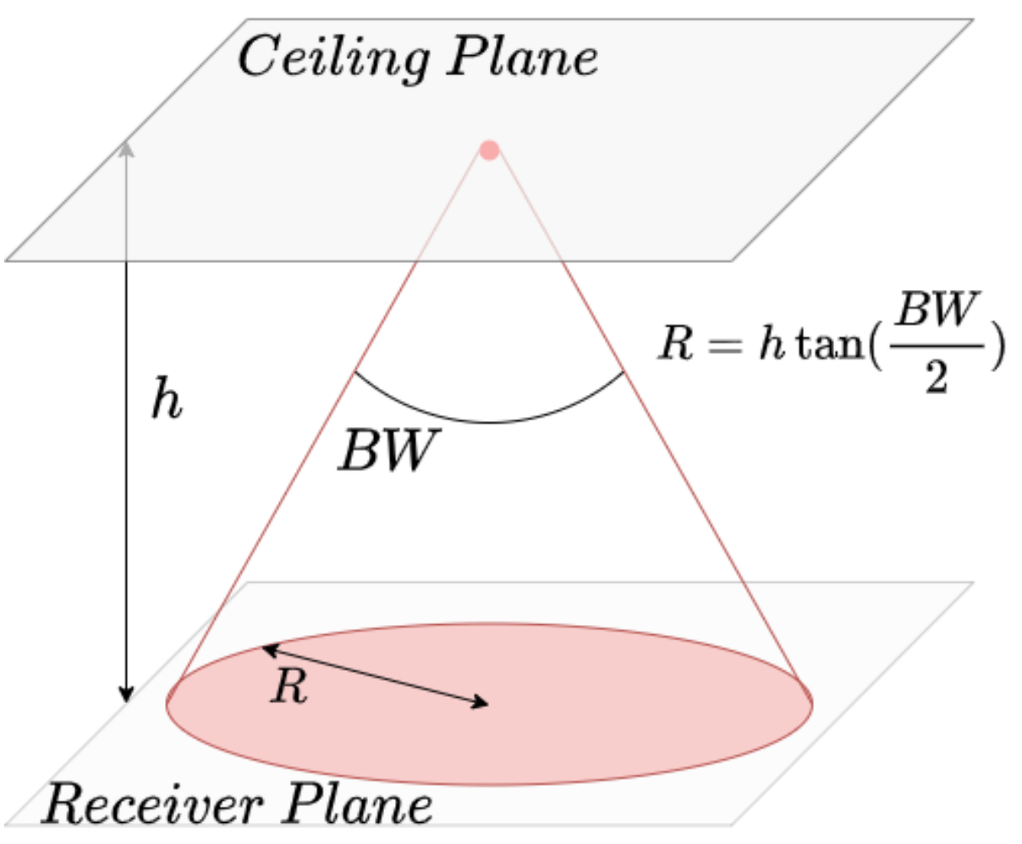
Visible Light Communication (VLC) could be provided by LEDs with low cost and high power efficiency by replacing or modifying existing lighting infrastructure.

To take advantage of the wide spectrum available to VLC and to mitigate interference, wavelength division multiplexing can be used to separate channels. However unlike RF, each separate channel will require a different LED and receiver to use. Receiver cost, size and power use are proportional to the number of wavelengths used and these factors could heavily affect uptake, most notably in the mobile device market.

So the objective of this project is to evaluate the minimum number of wavelengths that will be needed to guarantee effective communications in a VLC channel.



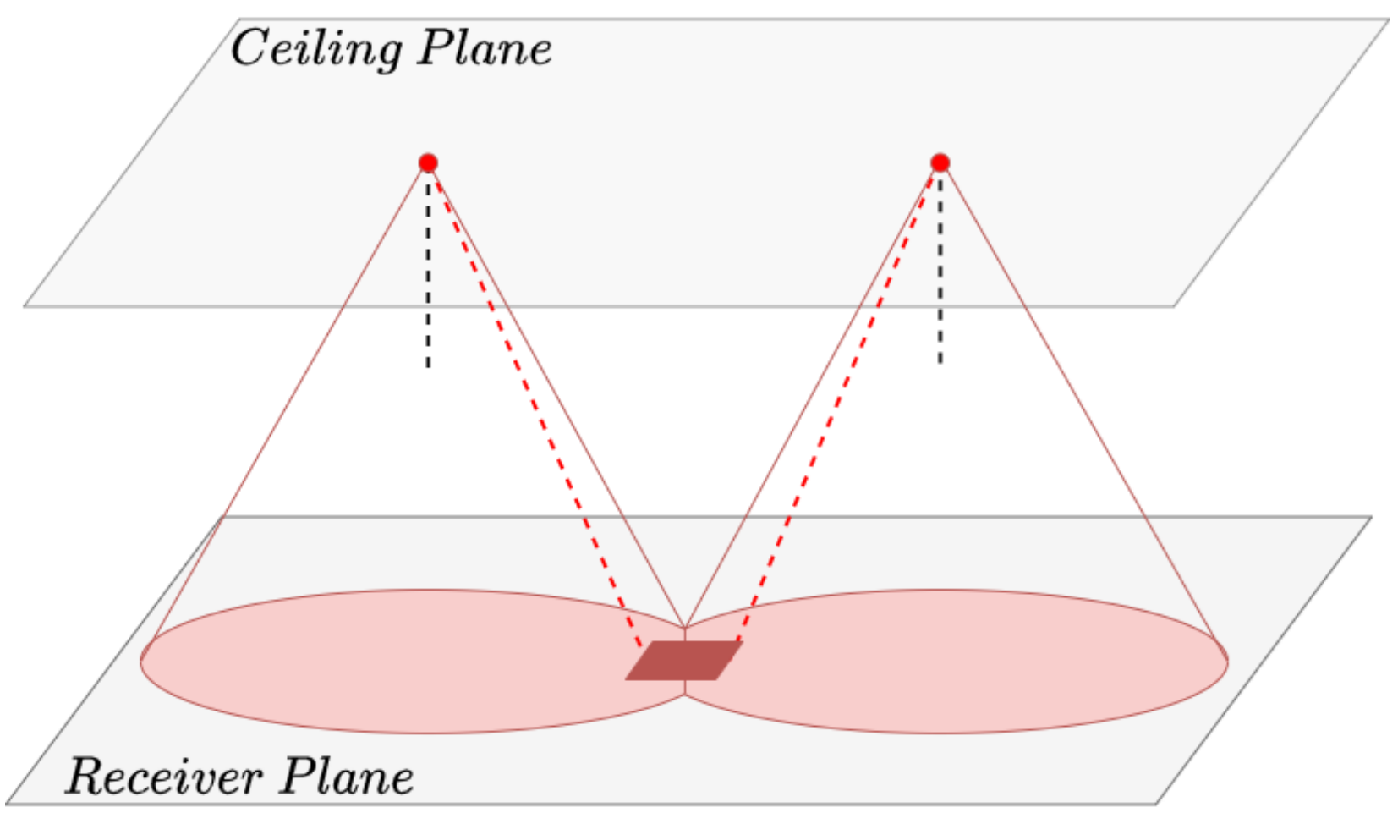
Cells



Each transmitter has a cell containing all the points which are better served (with a lower bit error rate (BER), representing the probability of error) by it than any other transmitter. To guarantee a minimum signal intensity, this cell is made to lie within the half-power beamwidth of the transmitter. The largest it can be is a circle with defined radius R.

The BER a receiver experiences is dependent on noise, a property of the receiver and background, and on interference which depends on how close the receiver is to other transmitters using the same wavelength.

If an axisymmetric receiver existed on the boundary between two cells using the same wavelength, it would not be able to distinguish between the two signals and would have a BER of at least 0.25. Therefore no two cells using the same wavelength can meet at any point.

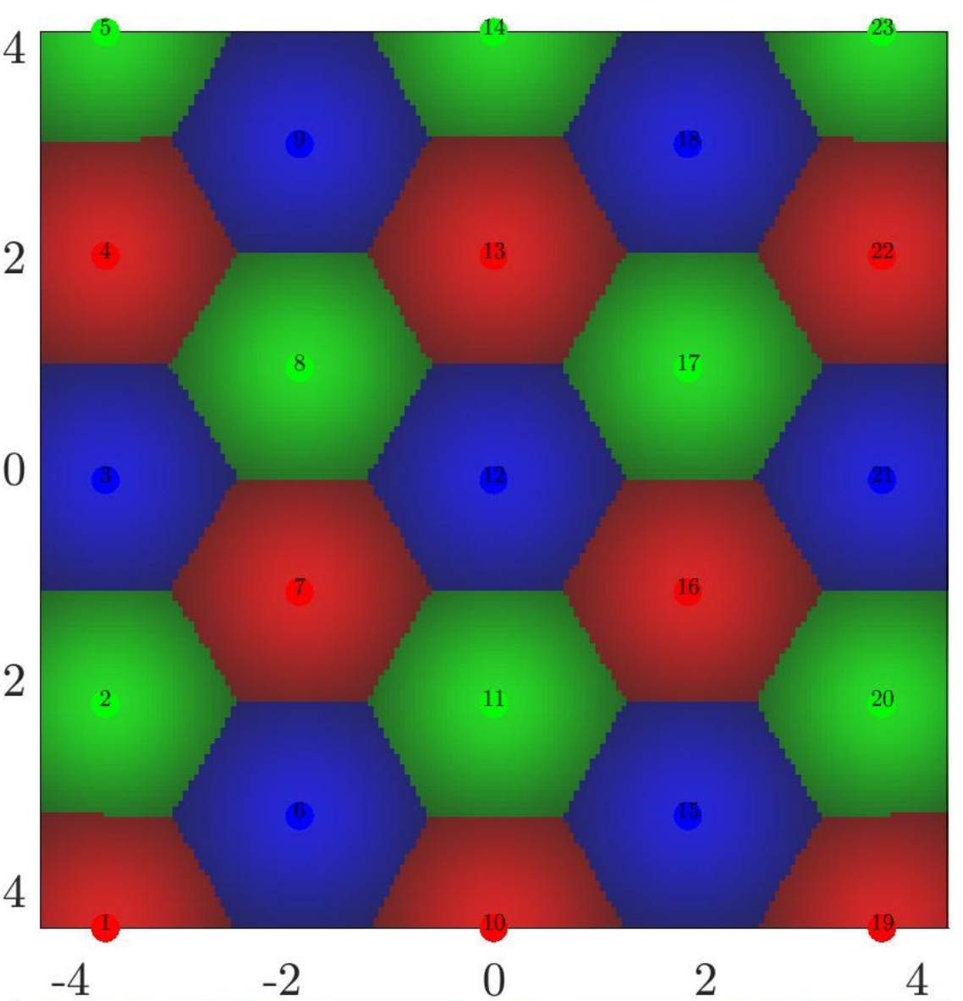


Cells using different wavelengths meet at lines of equal BER due to each transmitter. These lines bisect the locations of the transmitters provided that:

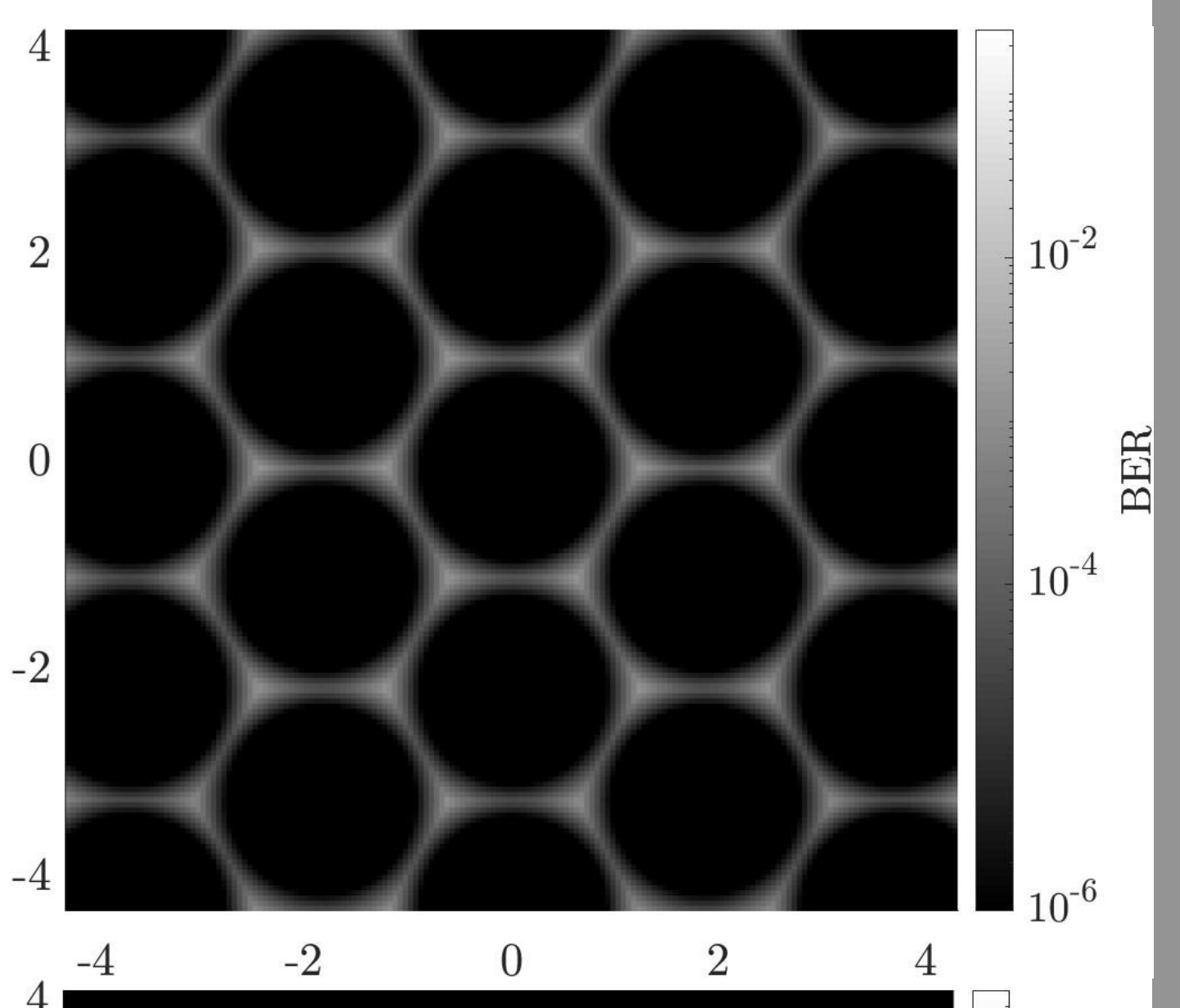
- Both transmitters use the same transmit power and beam width
- Interference is locally insignificant

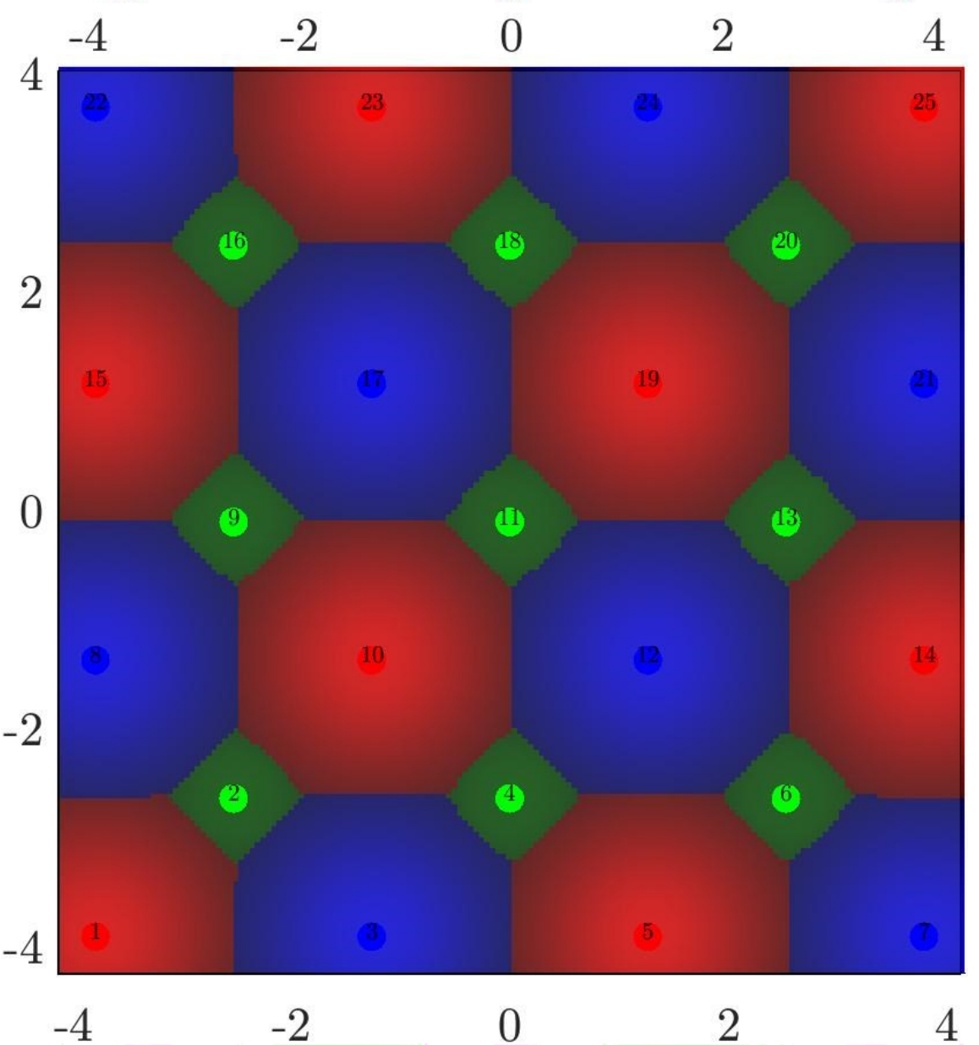
Three Wavelengths

Transmitters are best arranged in regular grids. Cells should tesselate and the maximum number of cells which meet at a point will determine how many wavelengths are needed. Three wavelengths is the geometric minimum needed to avoid two cells of the same wavelength meeting at a point. Signal intensity (left) and BER (right) are plotted over 2D position.



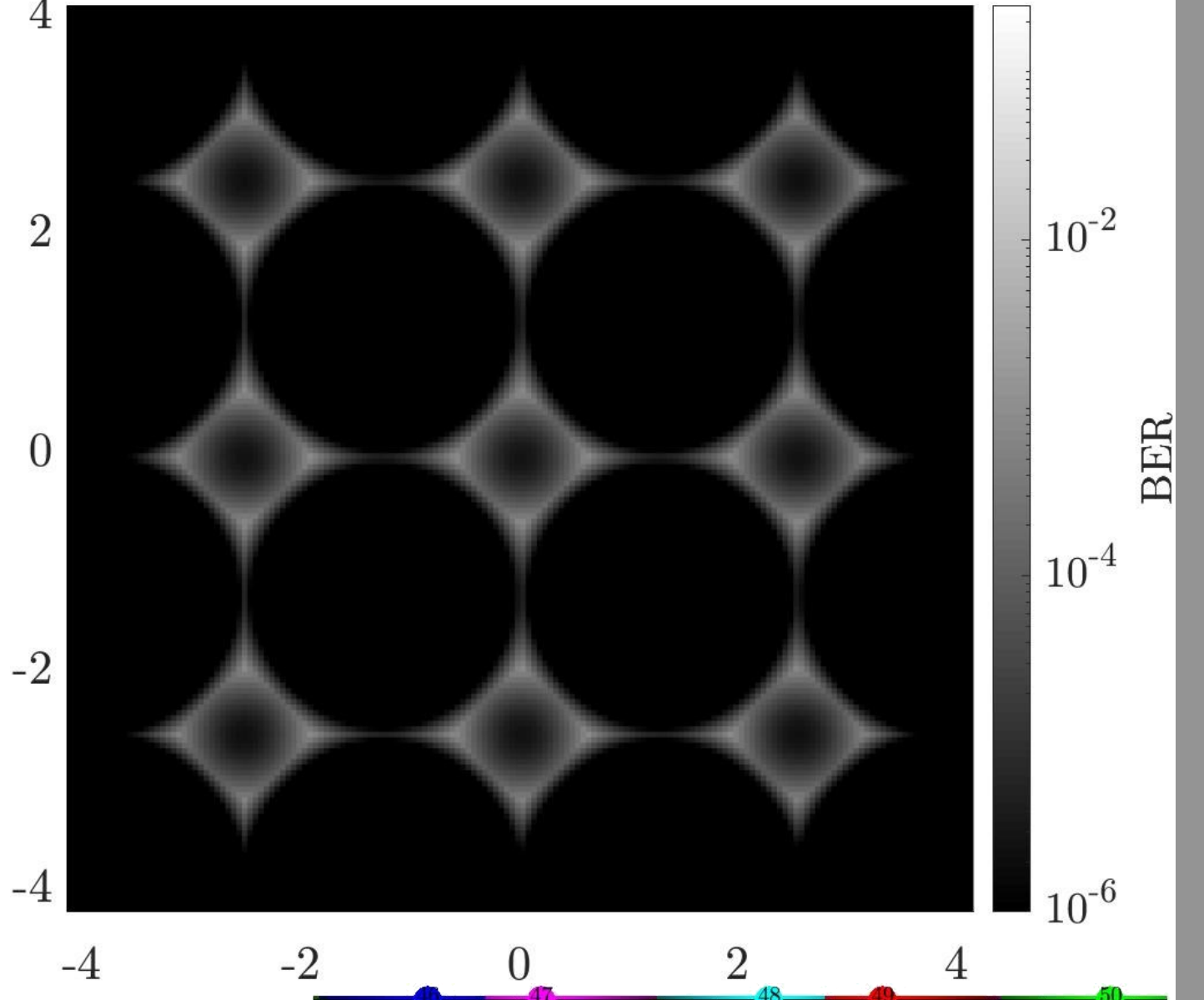
A hexagonal grid can provide communication using 3 wavelengths with low enough BER (1.68×10^{-3}) everywhere to use forward error correction (FEC) coding. This requires BER below ≈3.8×10^{-3}.

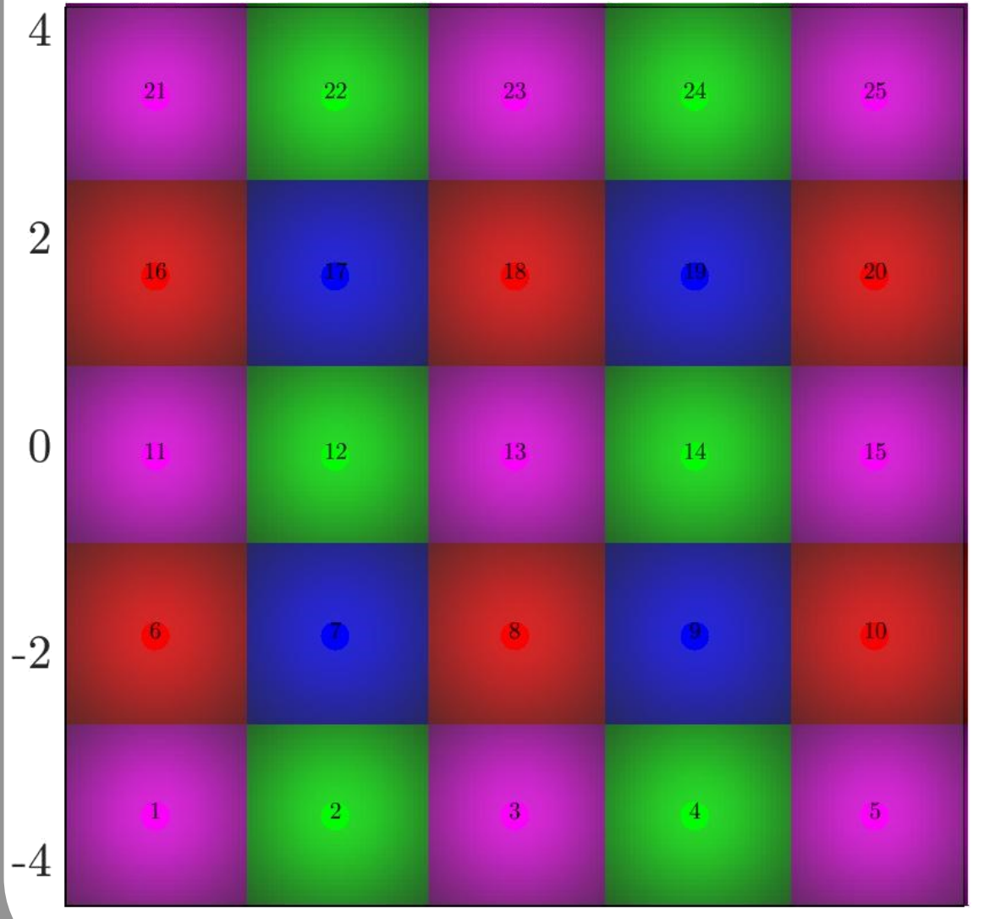




An irregular arrangement can be used to provide lower maximum BER (1.46×10^{-3}) with the same number of colours.

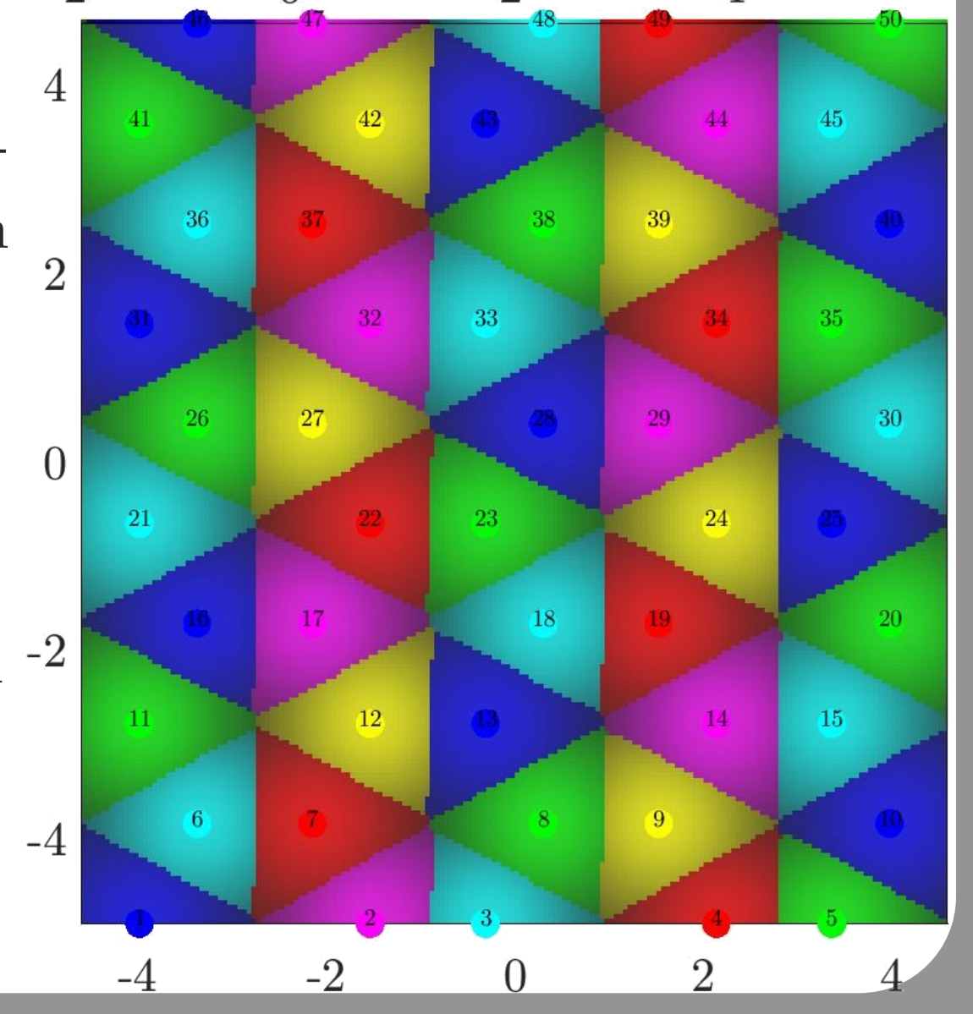
However this requires two different transmitter types with different beam widths and powers.



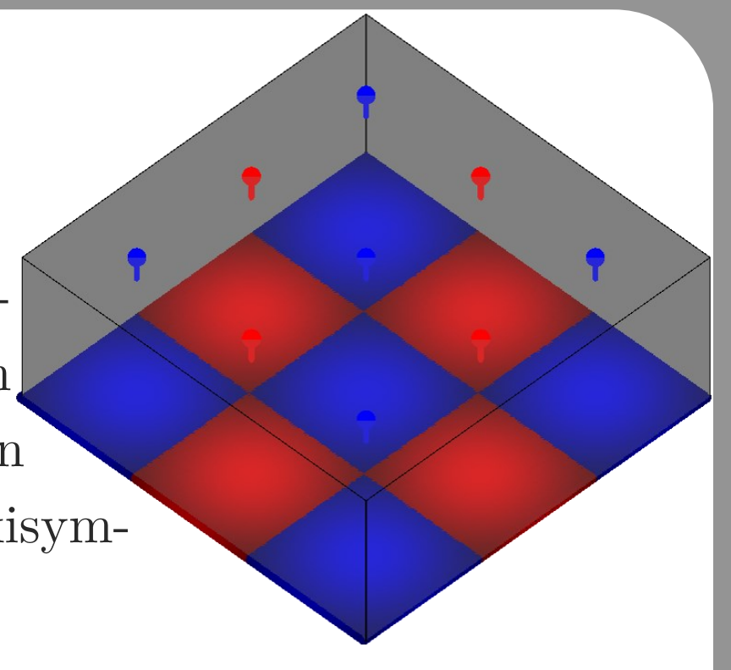


More arrangements (such as square or triangular cells) can be used but they result in only marginal performance improvements (20% reduction in BER) which likely do not justify their increased receiver complexity.

Therefore 3 wavelengths is the minimum requirement given receiver axisymmetry and the assumption that all transmitters are always on and transmitting separate data streams.



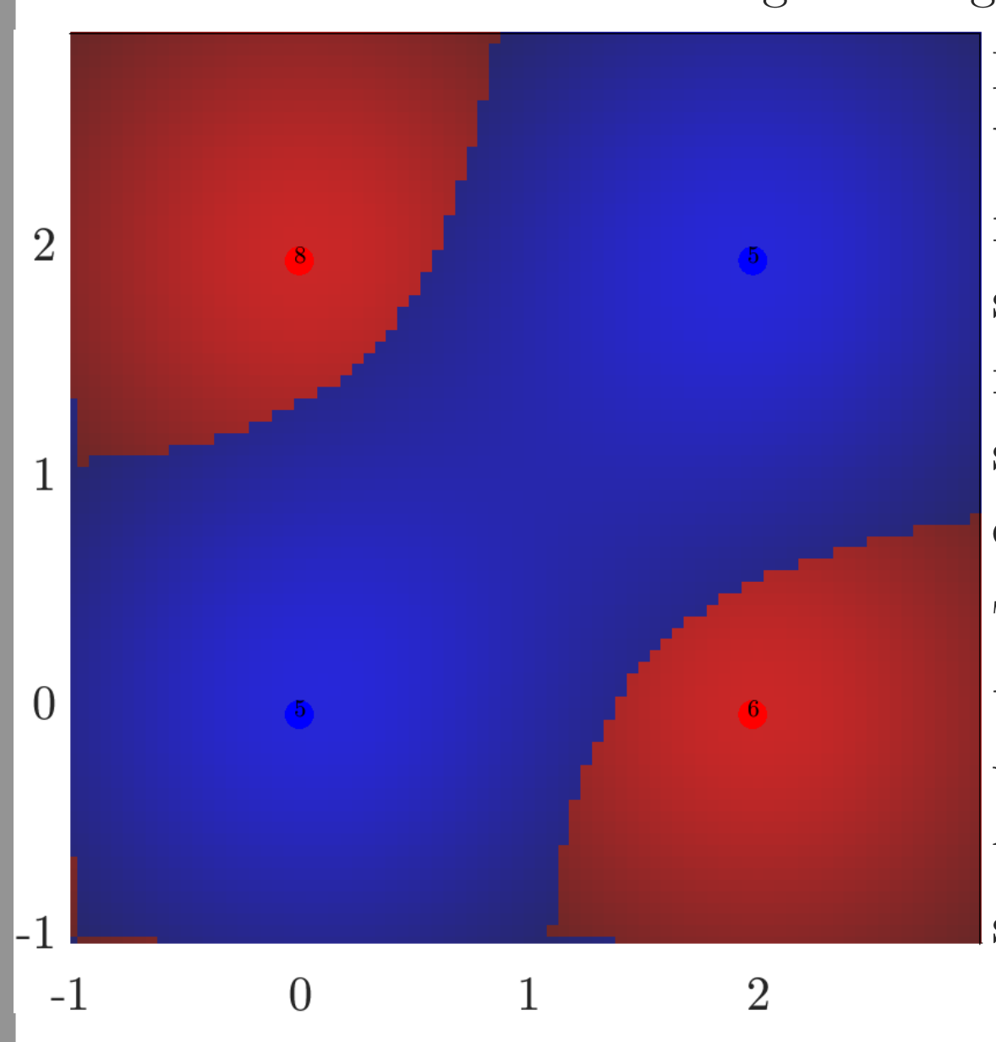
Two Wavelengths



Two wavelengths would allow an intuitive square grid to be used which is rotationally symmetric and easy to fit to rectangular rooms. Cells of the same wavelength touch at points in this arrangement, so other methods of mitigating interference are required which either mean that transmitters are not always transmitting separate data streams or receivers are not axisymmetric.

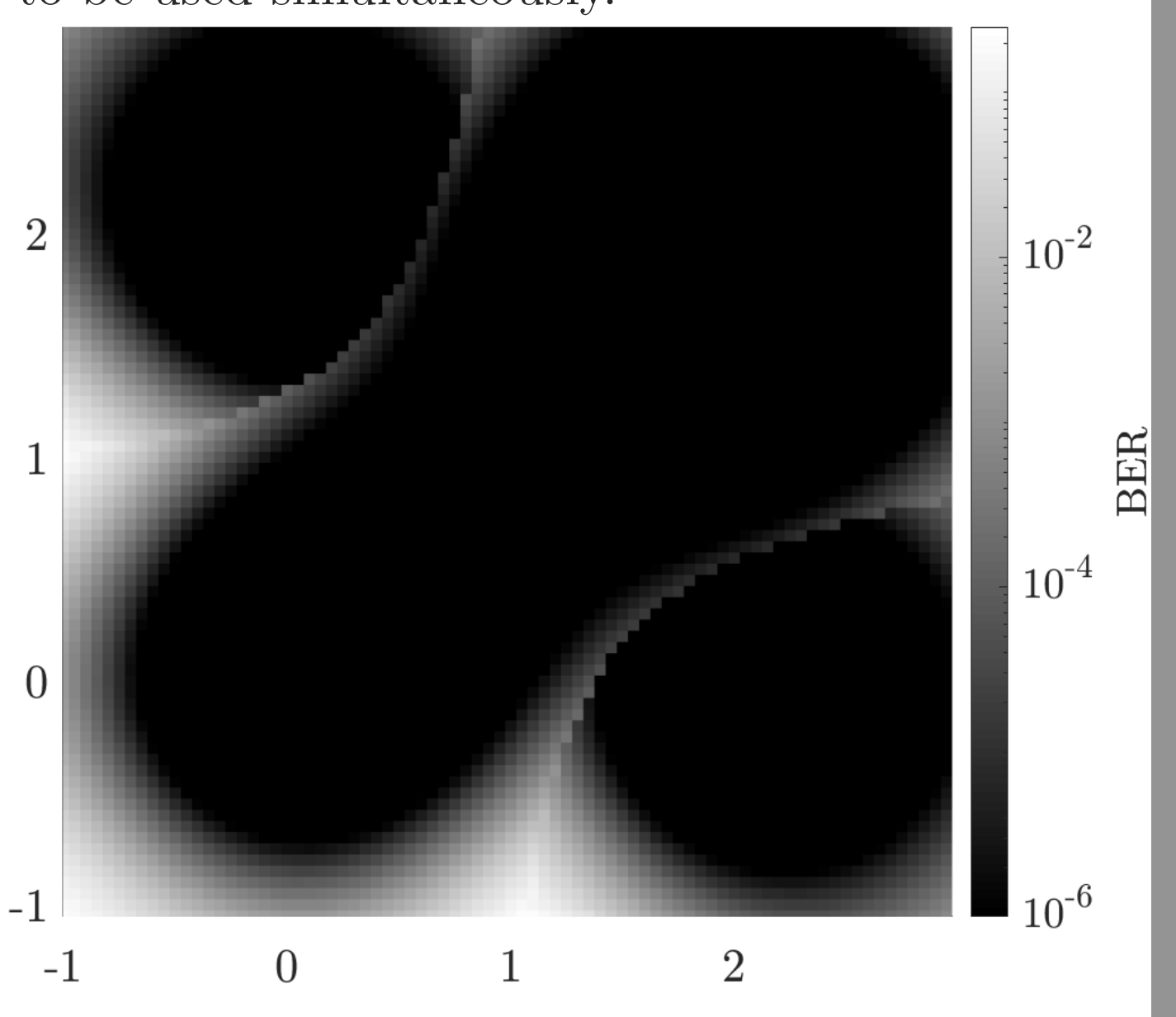
Transmitter management

If a transmitter is not in use, then it can avoid transmitting (other than necessary network maintenance data) and will reduce interference. However neighbouring interfering transmitters will need to be used simultaneously.



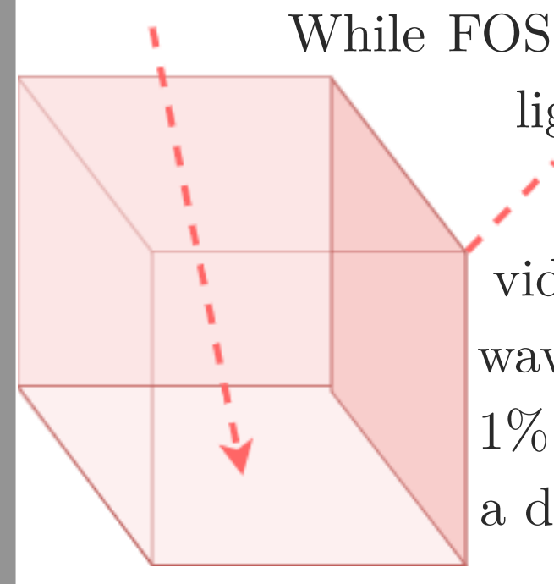
Interference in this scenario can be avoided by sending neighbouring interfering transmitters the same data, converting their interference into increased received signal power if decision feedback equalisation (DFE) is used.

This reduces the data rate each user experiences as multiplexing will have to be used to place multiple users' data on the same stream.



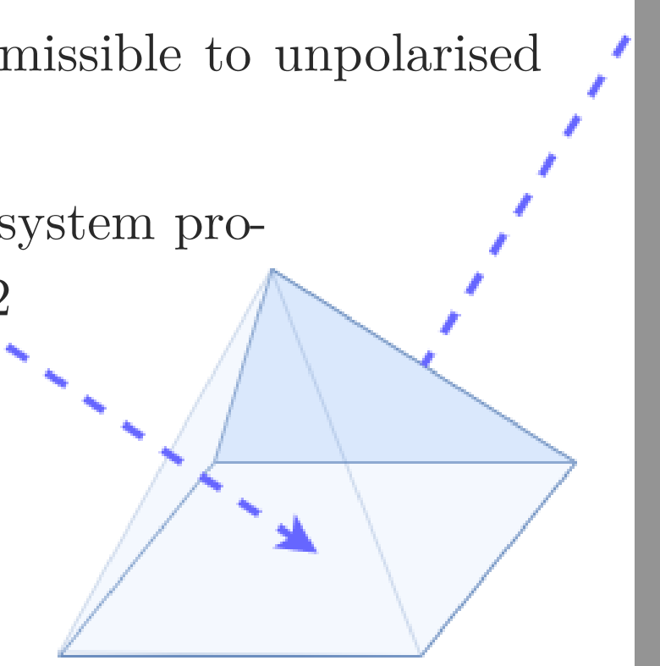
Adaptive receivers

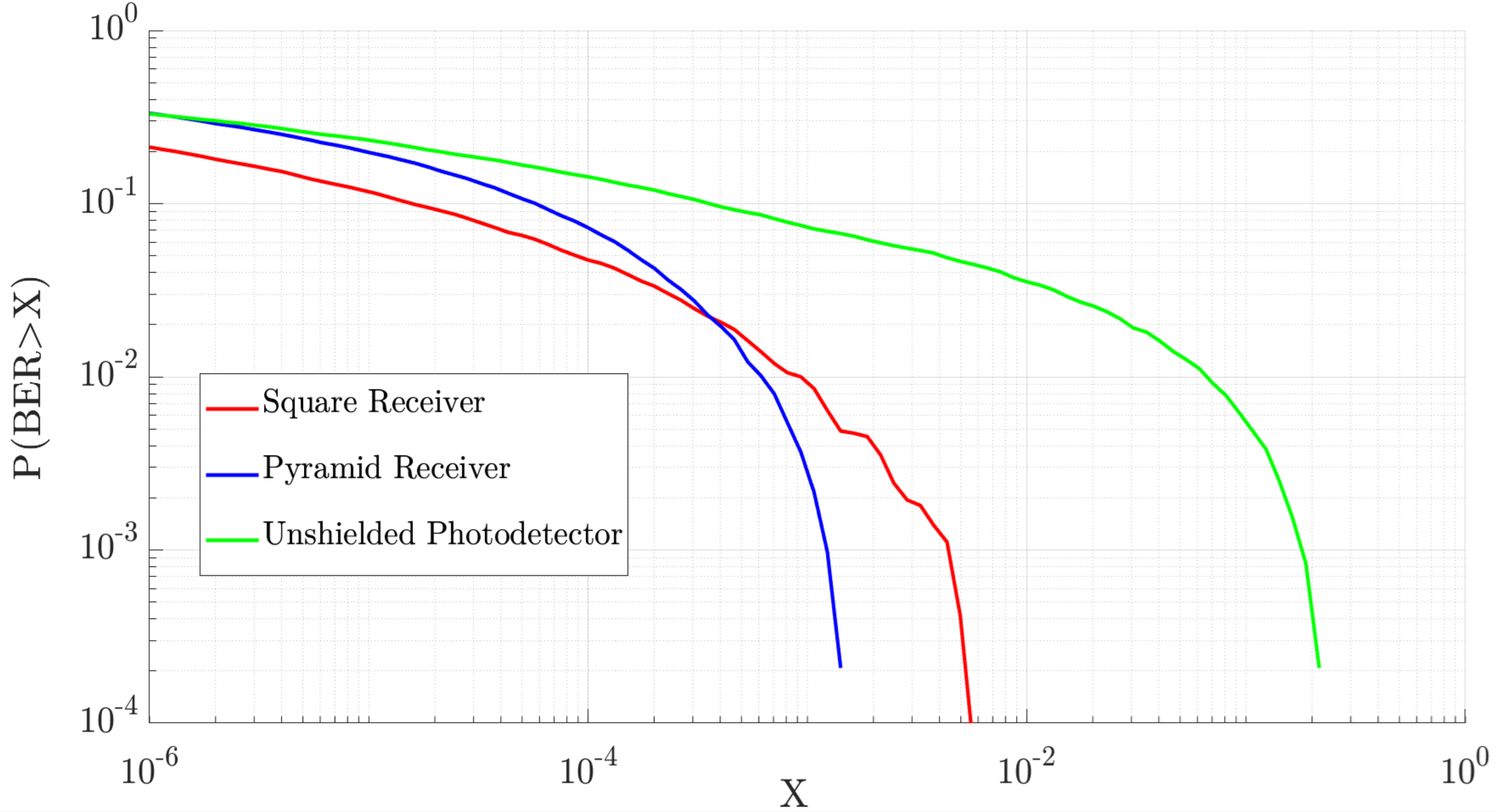
By using a photodetector which is surrounded in liquid crystal surfaces (known as fast optical shutters– FOSs) the axisymmetry of the receiver can be removed without reducing the likelihood that a receiver can 'see' a transmitter.



While FOSs are low-cost and can be made small, they are only currently ≈20% transmissible to unpolarised light, so reducing wavelength number requires increased transmitter power.

Forward error correction can be used to dramatically reduce the BER of a system provided that its original BER is less than ≈3.8×10^{-3}. Adaptive receivers make a 2 wavelength system viable by reducing the probability of BER>10^{-3} down to 1% or less. Adding FOSs (as in the geometries shown left and right) provides a dramatic improvement in BER compared to an unshielded photodetector.





Conclusion

With conventional receivers and without a transmitter management system, three channels is the minimum required and the improvement gained by using more does not justify the increased complexity.

Transmitter management can be used to make two wavelengths viable. By providing controllable shielding to the receiver, two wavelengths can be supported without a data rate reduction. This has important implications for the standardisation of wavelength division multiplexing of visible light communications systems in the coming years.

Acknowledgements

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