High Speed Train Communications Systems Using Free Space Optics

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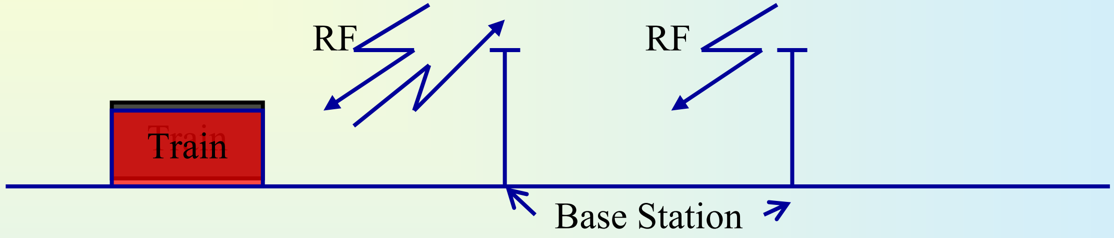
Outline

- Free Space Optics (FSO) – Introduction
- Proposed FSO Train System
- Over-ground Scenario
- Underground Scenario
- Numerical Evaluation of the System
- Communications Control
- Experimental Setup and Results
- Concluding Remarks

Introduction

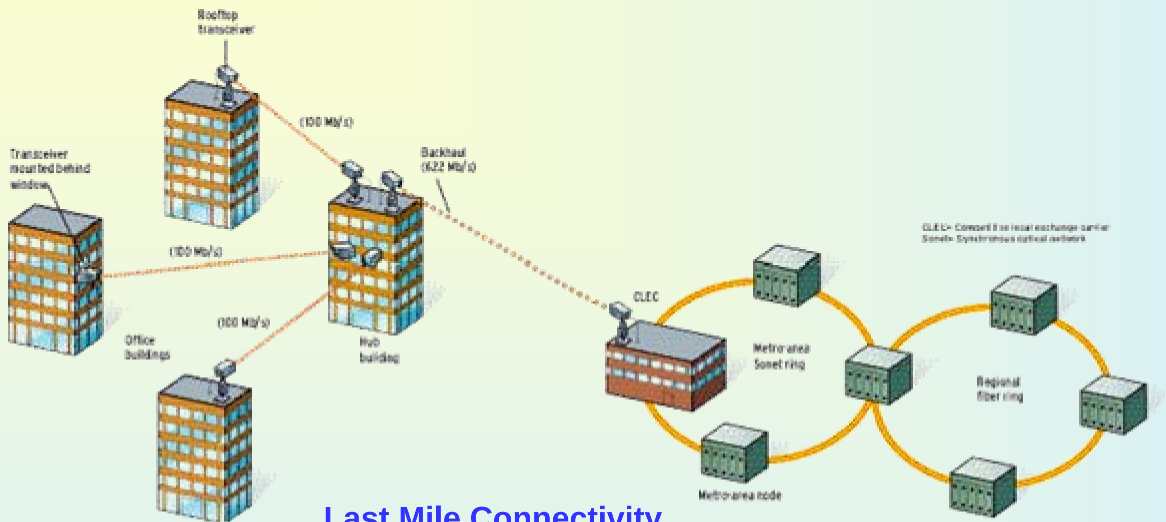
- Currently, radio frequency (RF) based communication systems provide broadband services in trains.



- **However**, end users require access to **high speed data** services.

- Alternative solution to the problem might be to employ **optical wireless systems/ free space optics systems** which can easily be connected to the high-speed fibre optic network.

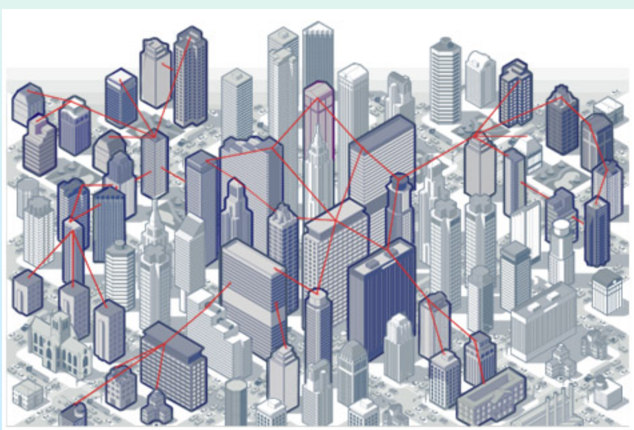
FSO - Applications



Last Mile Connectivity

Other applications include:

- Disaster recovery
- Fibre communications backup
- Video conferencing
- Links in difficult terrains
- Intelligent transport system (car-to-car Communications, ground-to-train communications)



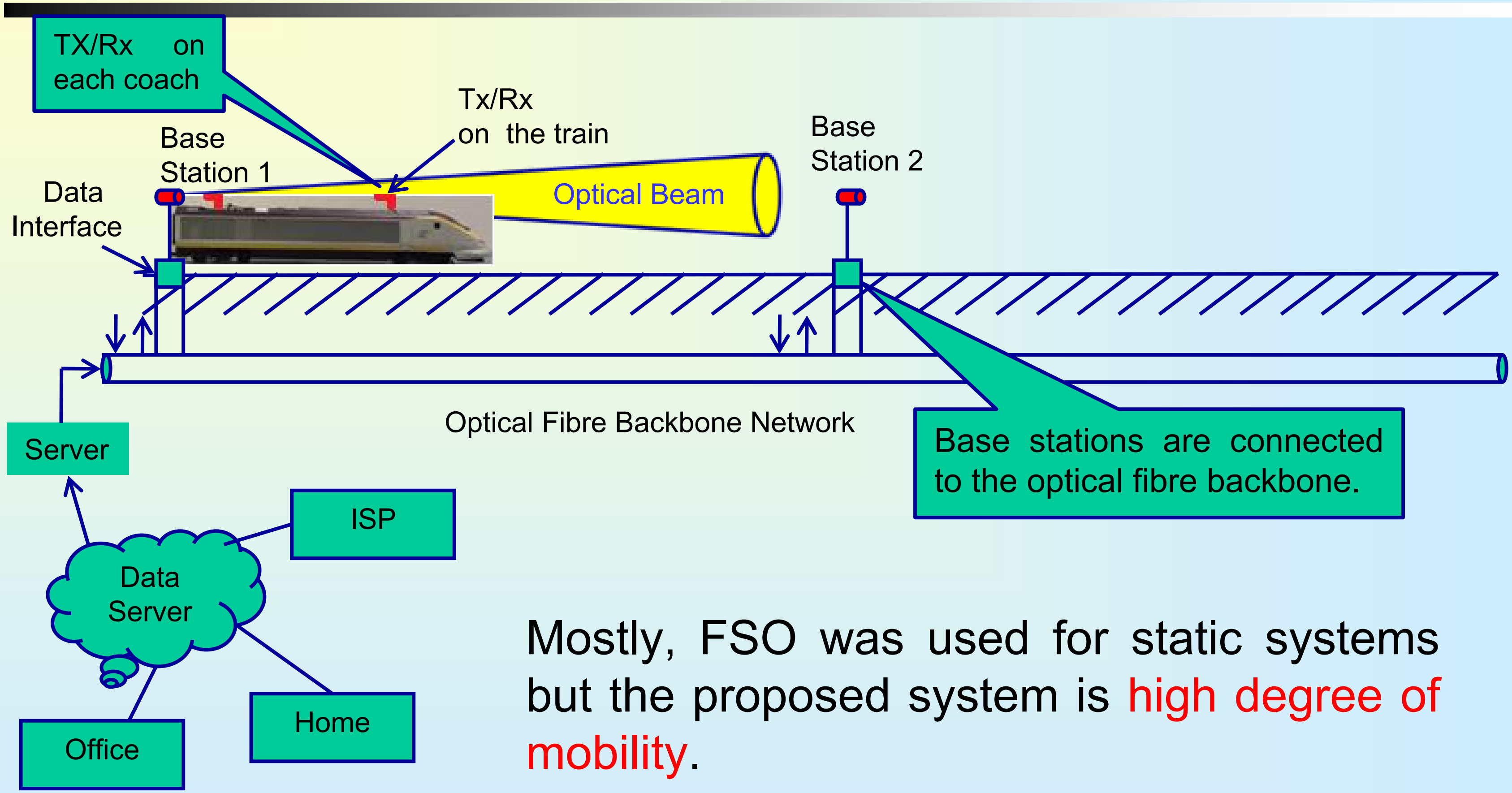
Multi-campus University

Hospitals

What Does FSO Offers?

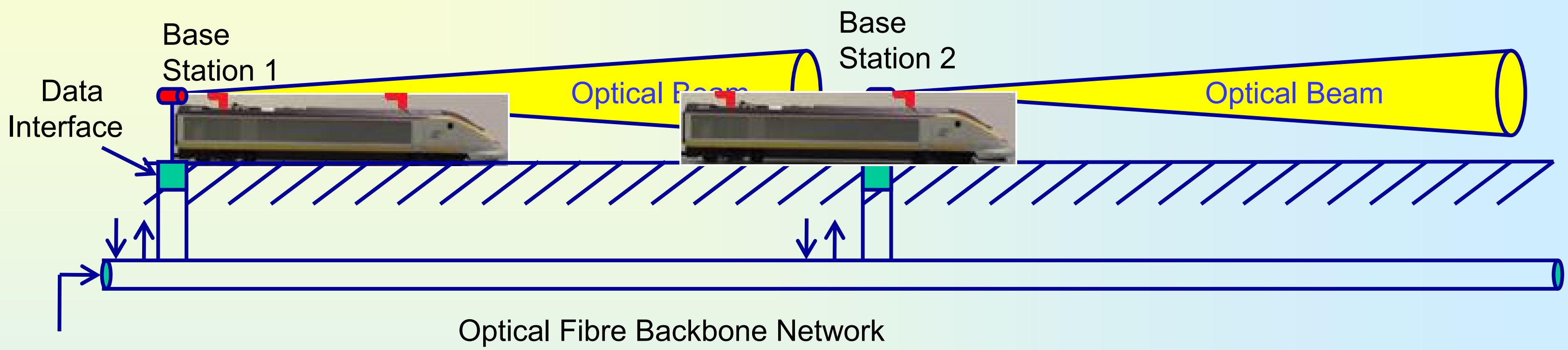
- Wide bandwidth offering high data rates
- No interference
- High Directivity
- Secure data transmission
- License free operation
- Compatible with optical fibre
- Quick to deploy

Proposed FSO Train System

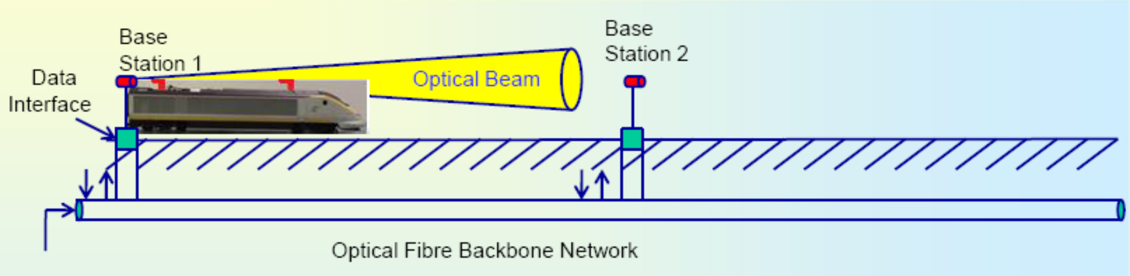


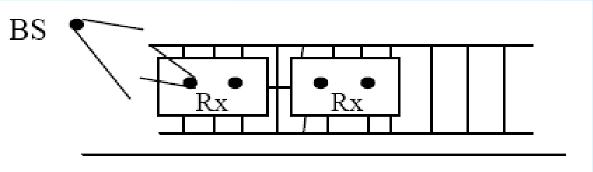
Mostly, FSO was used for static systems but the proposed system is high degree of mobility.

Proposed FSO Train System



Over-ground Scenario (1)





Top View

BS : Base Station
Rx : Receivers on the train

- Line of sight link is maintained between the base stations and the transceivers on the train.
- The received power decreases as the train moves away from the BS but increases when approaching the next BS.

Over-ground Scenario (2)

The **challenges** for the system are:

- Transmitted Power→ **Eye safety**

- Environmental Factors → fog, sunlight and turbulence .

The Criteria for the continuous communication is given by

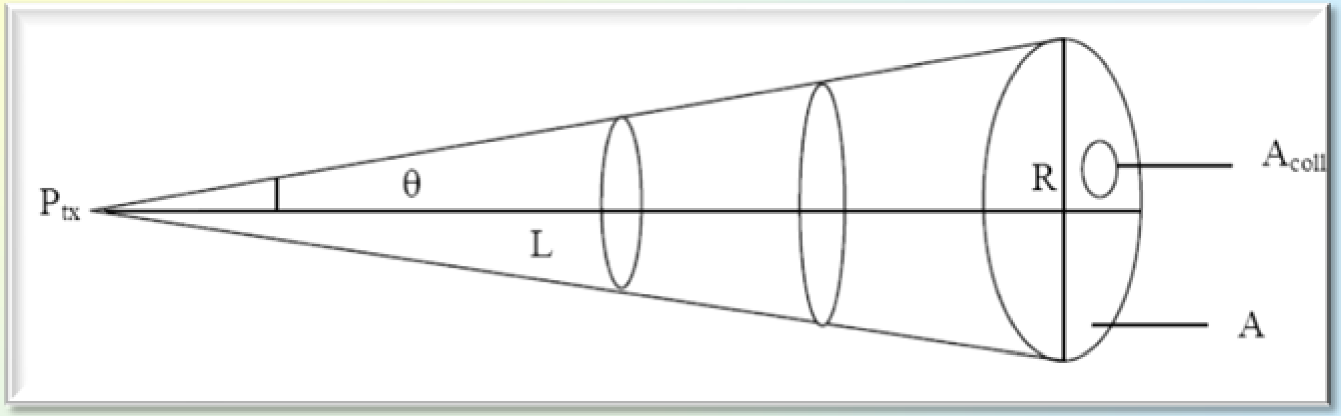
$$L_{BS} \leq L_{train} + L_{comm}$$

where L_{BS} is the separation between two consecutive BSs.

L_{train} is the length of the train and

L_{comm} is the communication link between the BS transceivers and that on the train.

Over-ground Scenario (3)-Optical Beam Profile



Variation of received power for over-ground condition

P_{tx} is the transmitted power from the base station.

$R = L \tan \theta$

$A = \pi R^2$

Optical power density $P_D = P_{tx} * A$

Received optical power $P_r = P_D * A_{coll}$

where;

R = Radius of the receiver beam

L = Distance between the transmitter and the receiver

A = Coverage area of the receiver

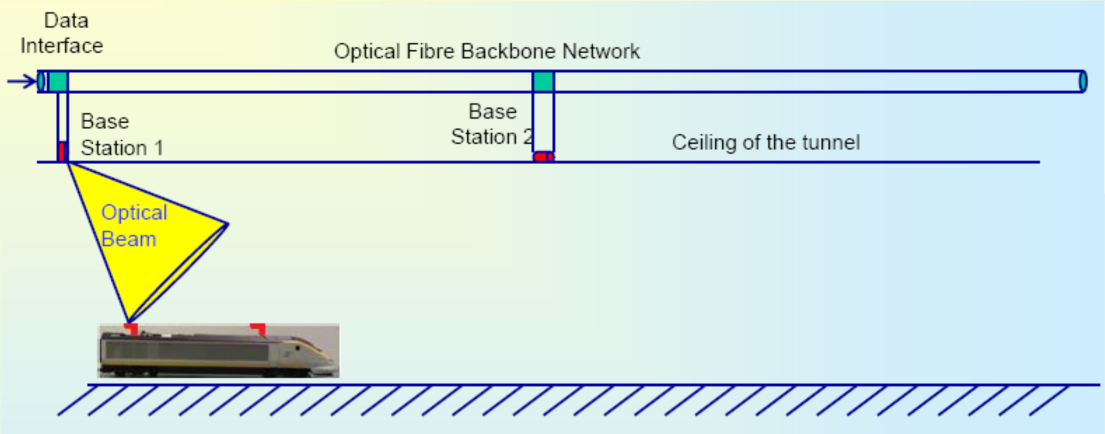
θ = Half angle of the transmitter

A_{coll}= Collection area of the receiver

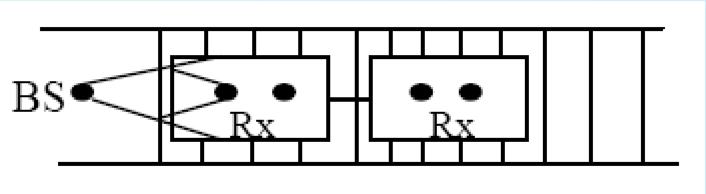
Parameters	Value
Receiver sensitivity	-30 dBm
Transmit power	10mW
FOV of transmitter	± 6^o
FOV of photodetector	± 60^o
Radiant sensing area of the receiver A_{det}	4.84 mm^2

Design Parameters

Underground Scenario (1)



Proposed underground train system

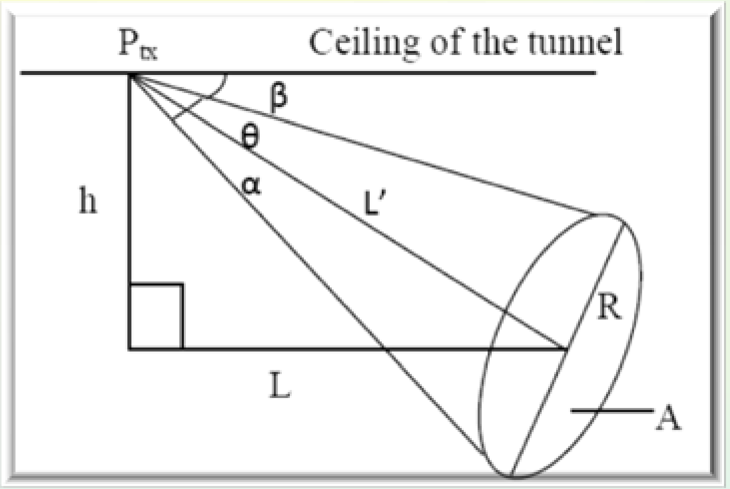


Top View

BS : Base Station
Rx : Receivers on the train

- In this condition, BSs are positioned on the ceiling of the tunnel.
- Communications is continuously maintained by an array of BSs located along the tunnel.
- Unlike the over-ground case, the received signal is not affected by environmental factors such as fog, sunlight etc.

Underground Scenario (2)



Evaluation of power for underground condition

L' : Axial distance between the transmitter and the receiver.
h : Height of the ceiling from the top of the train.

The design parameters used for the underground case is same as the over-ground case.

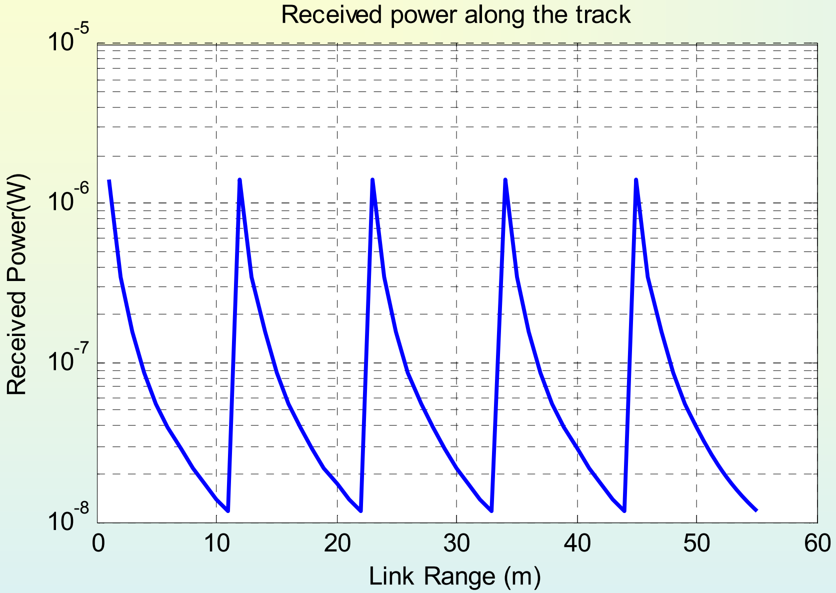
- The permitted transmit power could be greater than that for the over-ground case.

- $R = \sqrt{2} * L \tan \theta$

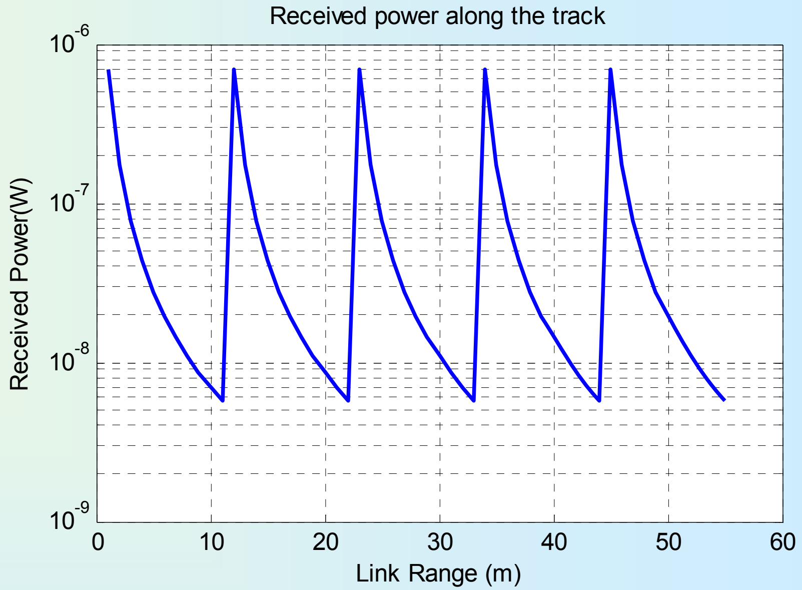
where R = Radius of the receiver beam
L = Distance between the transmitter and the receiver in horizontal direction.

- The received optical power is calculated as in the over-ground case.

Numerical Evaluation



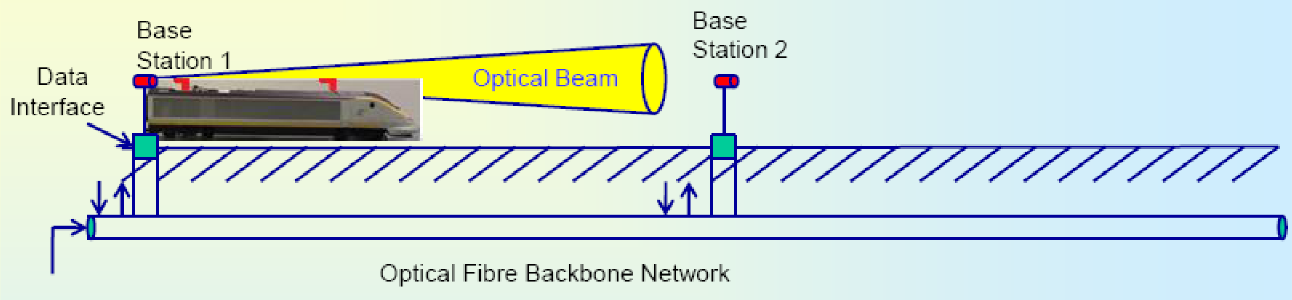
Received power variation for over-ground scenario



Received power variation for underground scenario

- Power variation for over-ground and the underground case is compared.
- Power received for the over-ground case is 3 dBm higher than that of the underground case.

Communications Control/Protocols

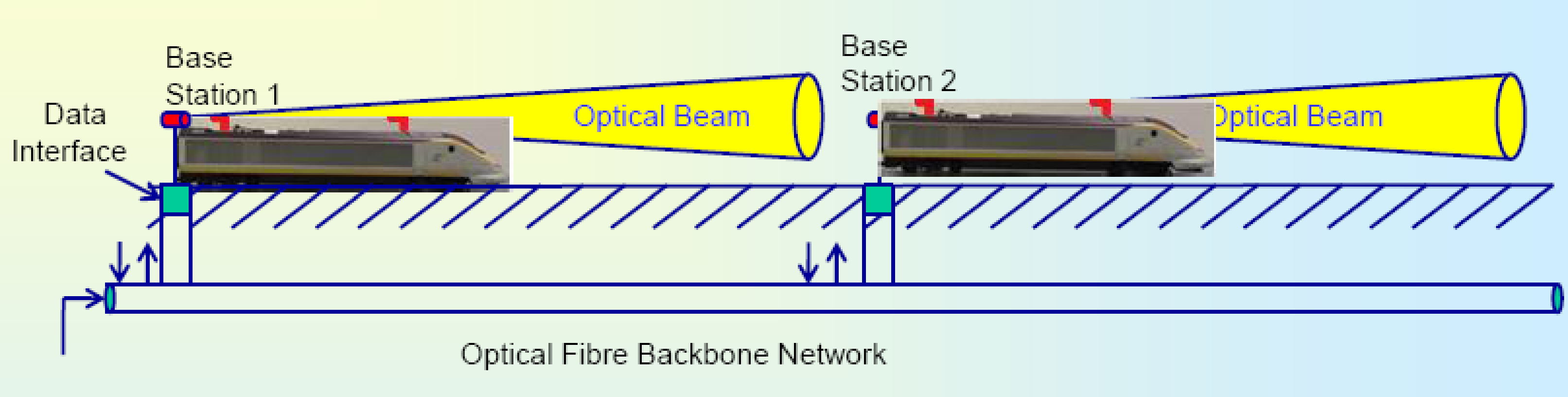


Protocol procedure for switching ON the proper BS.

(a) BS power control

- BSs are switched on as the train approaches them.
- When the BS senses the received power from the transceivers on the train, the closest BS is switched on.
- When the BS senses the fading of the signal, the BS is switched off.

Communications Control/Protocols



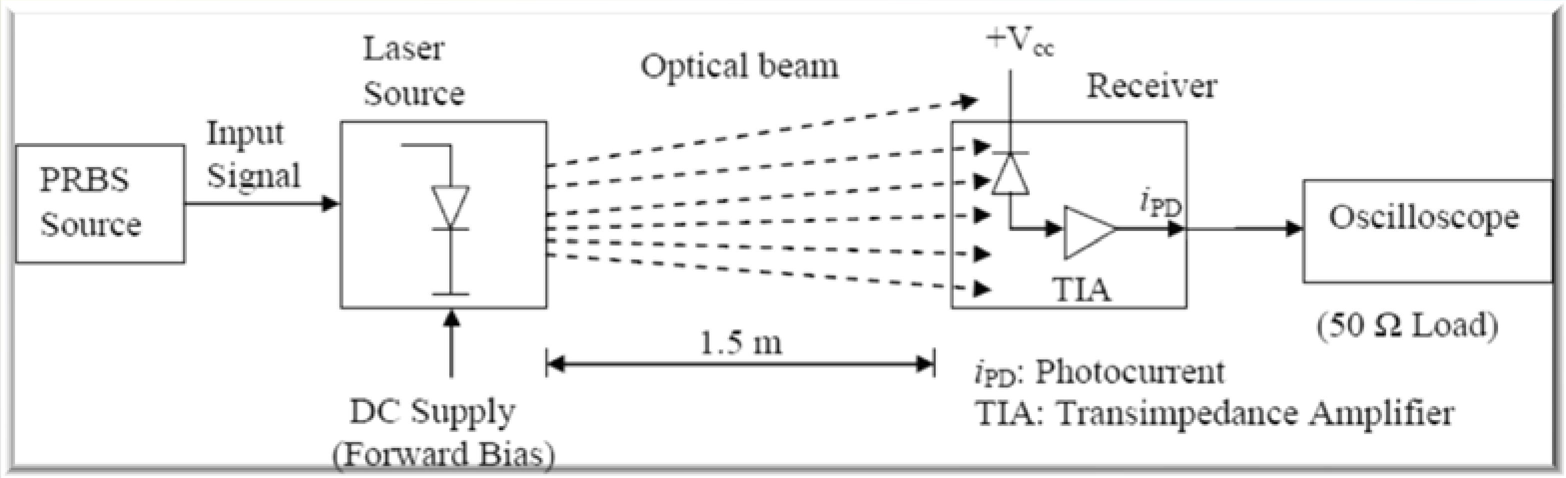
Protocol procedure when multiple trains share the same track.

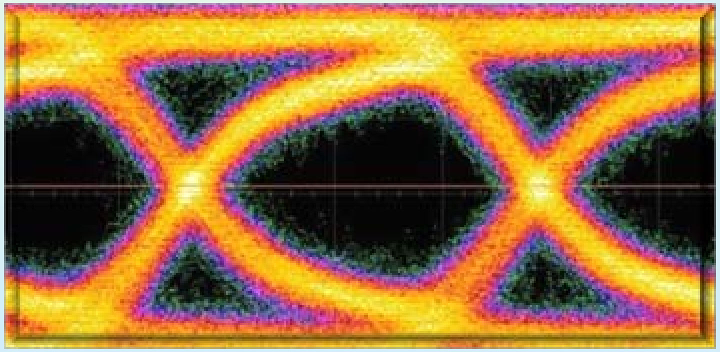
(b) **Data control**

➢When multiple trains share the same track, control procedure is required in order to prevent data collision.

➢This can be achieved by using Wavelength division multiplexing (WDM) or Time division multiplexing (TDM).

Experimental Setup and Results

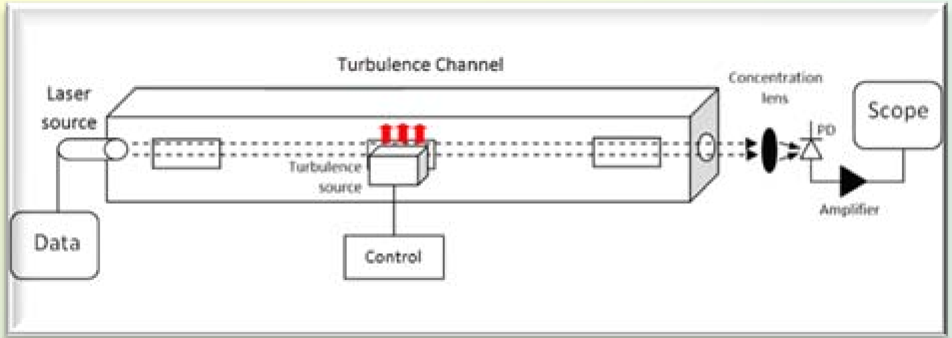




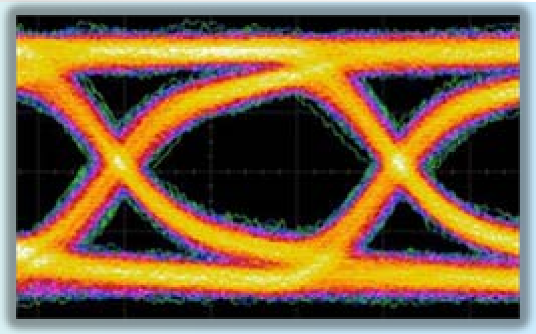
The Eye diagram of the received signal at 155 Mbps.

- The clear and wide opening of the eye width at a data rate of 155 Mbps demonstrates Bit Error Rate (BER) lower than 10^{-9}.

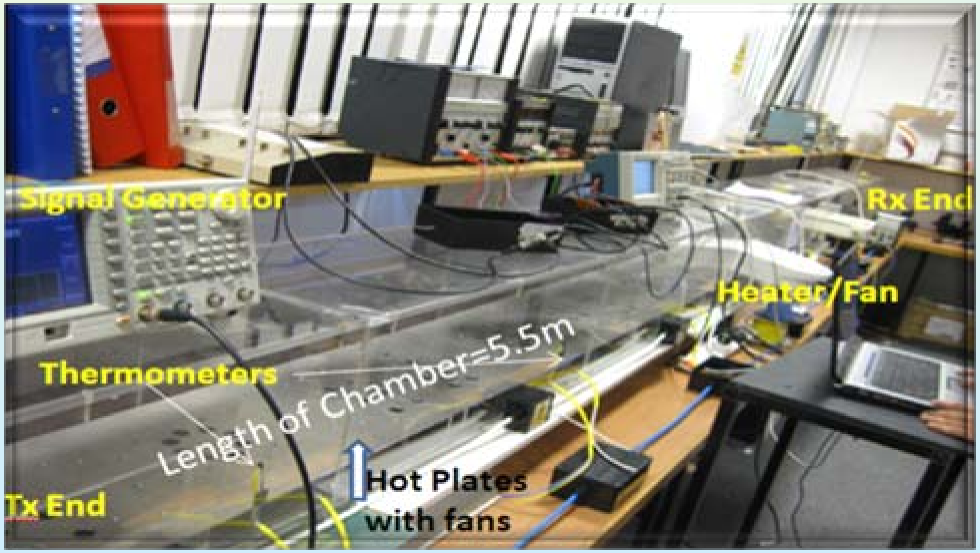
Experimental Setup and Results



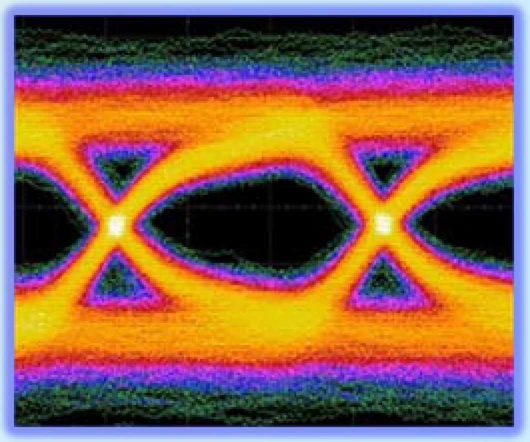
Block diagram of experiment setup



No turbulence @ 155 Mbps



FSO link setup in the laboratory with the turbulence chamber



Weak-medium turbulence @ 155 Mbps

H. Le-Minh, M. Ijaz, Z. Ghassemlooy, S. Rajbhandari, O. Adebanjo, S. Ansari and E. Leitgeb, accepted in *IEEE Globecom Workshop on Optical Wireless Communications*,2010.

Concluding Remarks

- FSO ground-to-train communications can offer Gigabit/sec data rate .
- The numerical evaluation of the system was compared for over-ground and underground scenarios.
- Improvement of optics system improves overall system performance.
- Communications control for the system was discussed.
- System performance with and without turbulence was investigated.

Future Work

- Testing the proposed system
  - Simulation.
  - Miniature system implementation in the laboratory.
  - Carry out the test in real environment.

Acknowledgement

- Northumbria University for supporting the research.

- OCRG and NCRLab for providing required software for simulation and practical workplace.

Thank You

Any Questions