Fast Tunable Lasers in Radio-over-Fiber Access Networks

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ABSTRACT

The authors present a novel concept of employing Optical Wavelength Packet Switching (WPS) in Radio-over-Fiber (RoF) access networks. The Central Station is equipped with a fast Tunable Laser (TL), which is externally modulated with a data signal upconverted to a radio frequency. The information transmitted over the network is encoded onto different wavelengths depending on the destination Base Station (determined by an Optical Band-Pass Filter at that BS). Routing of traffic could be performed on a packet-by-packet basis. In such a system dynamic bandwidth allocation could be realised by varying the time the TL transmits on a particular wavelength, depending on the amount of data that needs to be sent from/to the BS. The feasibility of employing TLs in the realisation of such a system is verified by building a basic WPS RoF system. The measurements of the cross-channel interference due to the TL wavelength instability and drift are also presented. No power penalty was observed due to switching of the laser, suggesting that RoF systems based on TLs are a feasible solution to the last mile problem.

Keywords: radio-over-fiber, tunable laser, optical packet switching, external modulation, fiber Bragg grating.

1. ITRODUCTION

Optical Wavelength Packet Switched Networks (WPSN) have drawn a lot of attention in recent years. This is caused by the ever-growing contribution of data traffic over voice traffic. As data signals have a burst nature, packet or burst switched systems are more suitable for their transmission. In times when wireless access (transmitting high-speed data) systems become a reality, one could expect that introducing packet/burst switching to such systems should also be beneficial [1, 3]. The wireless access networks are likely to be realised as Radio over Fiber (RoF) systems. In such systems, RF data signals would be modulated on to an optical carrier at a Central Station (CS) and then transmitted to a Base Station (BS) over fiber. By assigning a single wavelength to each BS in a cluster, it would be possible to feed numerous BSs using the same fiber (depending on the architecture). In such a system, WPS could be realised by employing a Tunable Laser (TL) transmitter at the CS. In order to send data to a particular BS the TL would tune to the wavelength assigned to this BS. The connection between CS and BS could be established by either sequential tuning of the TL to all wavelengths used or dynamic resource allocation could be employed. In the latter case, the TL could tune more frequently to an allocated wavelength of a BS that has more data to transmit or remain tuned to its wavelength for a longer time. For very busy wireless clusters more tunable transmitters could be employed in order to provide sufficient capacity. Data for different BSs could be then transmitted simultaneously using Wavelength Division Multiplexing. The simplified network architecture for WPS RoF system for star and ring configurations are shown in Fig. 1*a* and Fig. 1*b* respectively.

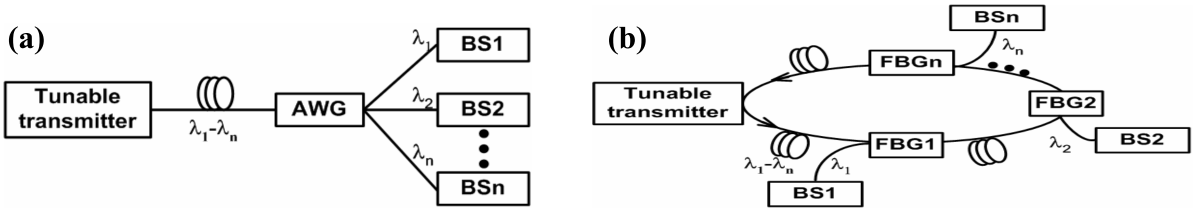

Figure 1. WPS network architectures (a) star, (b) ring.

In the case of a star configuration the transmitter is connected with a demultiplexer (e.g. an Arrayed Waveguide Grating (AWG)), which directs data sent on a particular wavelength to its destination. In a ring network each BS is preceded by an Add-Drop Multiplexer (e.g. Fiber Bragg Grating – FBG), which allows for the wavelength assigned to the BS to be dropped (downlink direction) and added (for uplink transmission). This configuration makes it possible to employ system solutions such as simultaneous demultiplexing and Single Side-Band (SSB) conversion (for dispersion mitigation) using one filter [3] as well as wavelength reuse [4]. Ring configuration is also more resistant to single connection failure, as the information could be sent in either direction.

In this paper we present an RoF system employing WPS. First a simple system using a single TL is built and its performance is verified. The basic TL properties and their impact on the system configuration are described. Next the two-transmitter system and the cross-channel interference due to the TL wavelength instability and drift in a WDM WPS network are presented.

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2. SINGLE TL SYSTEM - EXPERIMENTAL SET-UP AND RESULTS

The experimental set-up for the simple RoF WPS system is shown in Fig. 2. A TL is set to switch between three wavelength channels, separated by 50 GHz, 35 (1550.865 nm), 36 (1550.465 nm) and 37 (1550.0 nm) (as illustrated by the spectrum in Fig. 3*a*. The TL remains tuned to each wavelength for 500 ns. A trigger signal from the TL is applied to a Pulse Pattern Generator, which allows a burst pattern generation. The length and start time of the burst can be varied in regard to the switching time of the TL. For the experiments we used 350 ns burst generated every 1.5 µs and carrying 2.5 Gb/s data (Pseudo Random Bit Sequence (PRBS) length of 2^7-1).

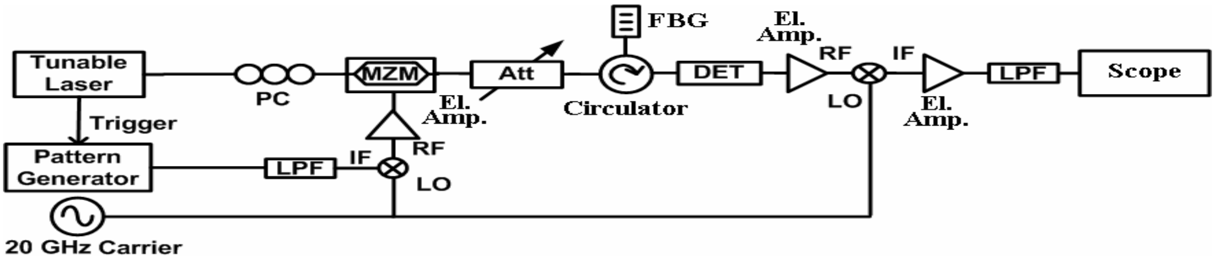

Figure 2. Single transmitter RoF WPS system - experimental set-up.

The burst data is passed through a Low Pass Filter (LPF) (to limit its spectral width) and upconverted to 20 GHz by mixing it with a signal from a Local Oscillator (LO). The RF signal is then amplified and used to externally modulate the optical carrier (channel 36). The data channel is then demultiplexed using an FBG in conjunction with an optical circulator. After photodetection the data is downconverted using an electrical mixer and a signal from the LO, amplified and filtered using an LPF. The eye diagram is then displayed using scope and the quality of the signal is verified.

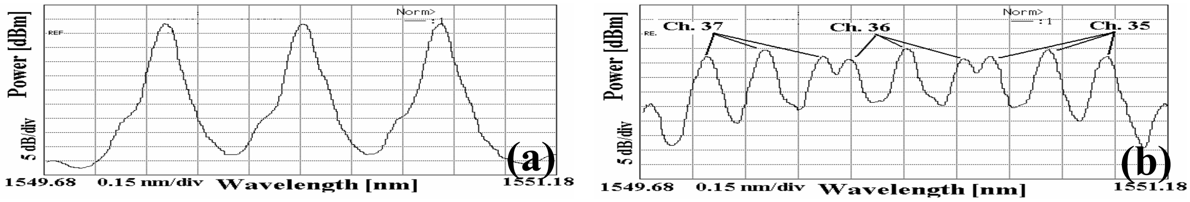

Figure 3. Optical spectrum of the TL switching (a) without modulation, (b) with modulation.

The optical spectrum of the TL under the modulation is shown in Fig. 3*b*. It can be seen from the plot that even though the data is modulated only on channel 36, all the channels have side-bands. This is due to the presence of the signal from the LO, which is continuously on. The optical spectrum of the demultiplexed channel 36 is shown in Fig. 4*a*.

There are a few aspects of the operation of the TL that need to be taken into account when employing these devices in a RoF distribution system. Some of them are: (1) the amount of spurious components generated by TL during the wavelength switch, (2) the tuning speed of the device and the time it takes for the laser to reach the destination wavelength (within a required range) and (3) wavelength stability. The first one is very important especially in a WDM system as the undesired frequency components generated during the tuning of a TL could seriously degrade the quality of signals transmitted on other WDM channels [5]. In RoF systems employing only one TL the spurious components could leak through an optical filter of a BS resulting in an interfering radio signals being transmitted by this BS. In order to avoid such a scenario the TLs used in our experiments have a Semiconductor Optical Amplifier (SOA) placed at the output of the laser, which can be turned off for a period of 50 ns from the moment the wavelength switching is initiated. This attenuates all the spurious components generated during the tuning of the laser, therefore avoiding any interference [6]. After this first 50 ns (blanking time) the TL is guaranteed to be within ±15 GHz from the desired wavelength.

As mentioned earlier, another important issue of the TL operation is the tuning speed and the wavelength drift (after emerging from the blanking time of the SOA). These parameters have a strong impact on the obtainable capacity of a system, as they determine the effective time over which the TL can transmit data. The faster the tuning speed the less time wasted on wavelength transition allowing more information transmission. Similarly, if after emerging from the blanking, the TL settles down at the destination wavelength without any wavelength drift it can be modulated straight away. However, if the wavelength of the transmitter is unstable in that initial time, it might be necessary to delay the data packet allowing the TL to stabilize before encoding data onto an optical carrier. Wavelength drift could also cause a inter-channel interference, if the drift is high enough for the signal to leak through an OBPF used to demultiplex the neighbouring channel. The influence of the wavelength drift will depend on the channel spacing, radio carrier frequency and the shape of the demultiplexer transfer function.

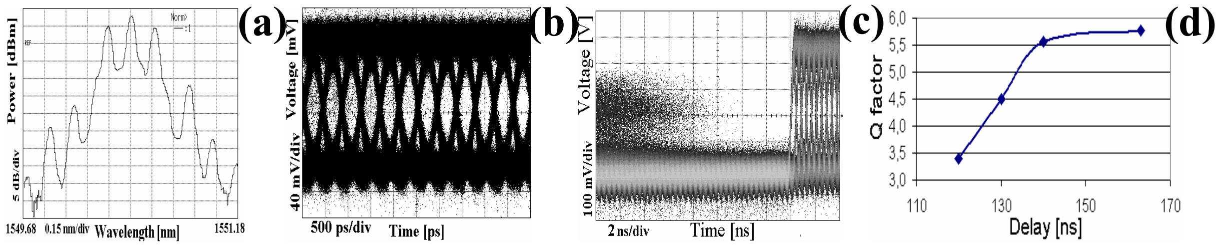

Figure 4. (a) Optical spectrum of the demultiplexed signal, (b) noise due to wavelength drift, (c) degradation of the signal due to wavelength drift , (d) Q factor vs. delay of the packet start time.

Figure 4*b* shows the received signal when the data was encoded onto the optical carrier immediately after the end of the blanking time. It can be seen that there is a significant amount of noise present in the received signal. Therefore, the start of the data packet has to be delayed in order to avoid signal degradation (see Fig. 4*c*). The variation of the signal Q factor (measured at the beginning of the packet) vs. the delay of the packet start time (from the end of the blanking time) is shown in Fig. 4*d*. It can be seen from the plot that the signal quality improves as the delay is increased up to 140 ns. After that the Q factor converges to a maximum value (around 6). The origin of this noise is caused by the wavelength drift of the TL. Figure 5*a* presents the results of a frequency drift of the TL vs. time (from the moment the blanking was turned off) measured using a self-heterodyning method [7]. It can be seen from the plot that when the TL emerges from the blanking time, its wavelength varies from the target value by around 10 GHz and this difference is reduced to 2 GHz after around 160 ns. Such drift causes the signal to experience different attenuation while passing through the OBPF, resulting is a significant level of noise at the output of the detector.

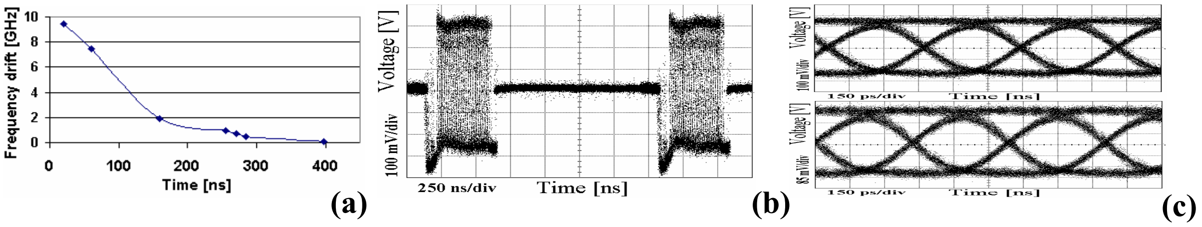

Figure 5. (a) Frequency drift of the TL vs. time,(b) received data packets,(c) eye diagram of the received signal: top - continuous data, bottom - burst data (TL switching) (optical power falling at the detector -7 dBm).

Figure 5*b* shows the oscilloscope traces of the received data packets. In order to avoid the degradation of the signal the data packet has been delayed by 140 ns from the time the wavelength switch has been initialised. Figure 5c illustrates the eye diagrams of the received signal when the TL is operating in a continuous mode (no switching – top) and when burst data is transmitted (with the TL switching – lower plot). There is no difference in signal quality observed.

3. TWO TL SYSTEM - EXPERIMENTAL SET-UP AND RESULTS

In order to verify the usefulness of TLs in a WDM RoF network the system comprising two lasers was investigated. The experimental set-up is shown in Fig. 6.

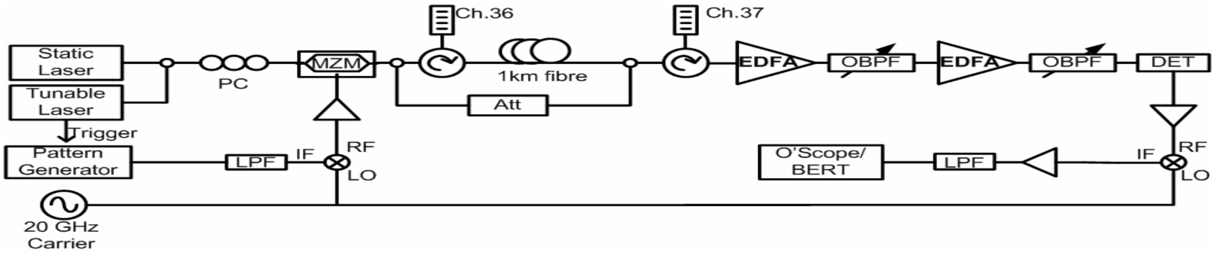

Figure 6. WDM WPS RoF system - experimental set-up.

In this case one TL and one static laser were coupled together and then externally modulated with a 2.5 Gb/s data upconverted to 20 GHz. The TL was tuned between channel 30 (1552.8) and channel 36 and the static laser was set to transmit on channel 37. The static laser was then demultiplexed and the Q factor of the received data was measured. Because both lasers were carrying the same data it was necessary to decorrelate the information transmitted. This was done by filtering channel 36 and sending it over an appropriate length of fiber, before recombining it with the fixed laser.

The optical spectrum of the two signals as well as the scope trace showing the received data packets when the TL was enabled (top) and disabled (bottom) are shown in Fig. 7*a* and Fig. 7*b* respectively. From the latter it can be seen that there is no noticeable difference in the quality of the signals received. In order to verify this we measured the *Q* factor of the channel 37 at various moments of time across the data packet when the TL was switched on and off. No penalty due to the tuning of the laser was observed. This means that the wavelength drift was too small to cause any interference between the two channels carrying 20 GHz signals and spaced by 50 GHz. As the RF frequency increases the distance between the sideband will reduce and the probability of interference will increase. Nevertheless, it could be expected that RoF will portray a better immunity to such sort of degrading factors than the systems carrying base-band data. This could be attributed to the fact that any portion of the signal (in our case from channel 36) leaking through the pass-band of the optical filter will beat with the optical carrier (of channel 37) to generate a different RF component than the desired signal. This component could be then filtered out using an electrical LPF at the destination. Therefore wavelength drift of the TL would pose a real problem only when it would cause the sidebands of the neighbouring channels to come very close to each other (within the pass-band of the electrical LPF).

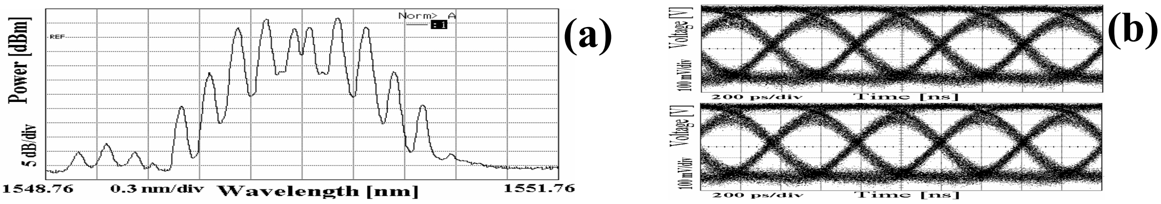

Figure 7. (a) Optical spectrum, (b) scope trace of the received data with TL: enebled - top, disabled- bottom.

COLCLUSIONS

A demonstration of a RoF WPS network was presented. The system employed a TL, which could transmit data packets on different wavelength depended on the destination BS. It has been shown that even though the TL could be tuned very quickly (50 ns) it required an additional 140 ns settling time before the data could be modulated on the desired wavelength.

A two transmitter system was also demonstrated. The influence of the TL wavelength drift on the neighbouring channel was investigated. The *Q* factor measurements showed that there is not degradation in signal quality due to TL tuning. This proves that TL transmitters could be used in a WDM RoF systems without causing interference.

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