SYSTEM DESIGN CONSIDERATION FOR A UNIVERSAL SCALABLE POINT-TO-POINT RADIO

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ABSTRACT: A low cost universal scalable point-to-point radio platform ranging from 6 to 38 GHz has been developed. This paper discusses the features, the system design constraints and the performance tradeoffs of this radio. TRuepoint® 5000 radio can be programmed to carry any combination of PDH/SDH (SONET)/Ethernet data with airlink capacity between 4 Mb/s and 180 Mb/s, channel separation between 2.5 MHz and 56 MHz, and modulation between QPSK and 256 QAM to meet any spectrum utilization efficiency requirements. Transmit and receive carrier frequencies are independently programmable to satisfy any standard and most odd frequency plans.

KEYWORDS: System architecture; Adaptive equalizer; Amplitude response; Error correction; Modulation; Phase-locked loop.

1. INTRODUCTION

Mobile phone operators prefer that their backhaul microwave radio be scalable, and deployable for all capacities, all authorized bandwidths, and all frequency bands with a minimum number of spares. Harris Stratex TRuepoint® 5000 is an industry first point-to-point universal scalable radio platform.

To satisfy these universal scalable radio performance requirements at reasonably low cost, some design trade-offs are necessary.

It is expensive to have a "perfect" RFU (Radio Frequency Unit) to transmit high level modulation signals. With advanced signal processing technology, some signal degradation due to imperfection of the RFU can be mitigated. By incorporating powerful FEC and adaptive equalizers, some of the RF parameters specifications can be relaxed.

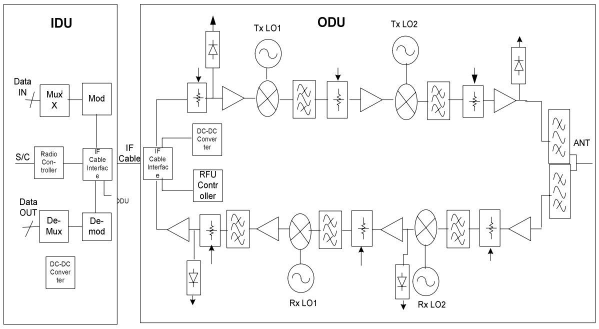

Figure 1: Block Diagram of the Radio

2. SYSTEM ARCHITECTURE

This scalable radio is partitioned into IDU (SPU) and ODU (RFU). The interconnection between the IDU and the ODU is through a single industry-standard coaxial cable. Among others, the IDU performs the functions of modulation, demodulation, multiplexing and de-multiplexing. It also provides customer tributary access and network management tool access. The ODU performs the up and down-conversion and all other RF functions. Figure 1 shows the simplified block diagram of the radio. Figure 2 shows 1+1 protected radio configuration.

Figure 2: 1+1 Protected TRuepoint® 5000 radios

3. SYSTEM REQUIREMENTS

A scalable radio has to be fully programmable in terms of capacity and modulation. Since it has to carry any combination of PDH/SDH (SONET)/Packet data rate between 4 Mb/s to 180 Mb/s and modulation level between QPSK and 256 QAM, many additional requirements need to be implemented comparing to that of radios designed only for low capacity with low level modulation or radios designed only for high capacity with high level modulation. This scalable radio must have a high system gain. It also requires a high receiver dynamic range to accommodate low capacity with low level modulation systems. Furthermore, the radio must have a wide agility. In order for the same radio to be used for different T/R channel spacings in any frequency band, transmit carrier frequency and receiver carrier frequency must be independently programmable. It must have good adjacent channel interference sensitivity for all the supported configurations. Other system requirements include full support of equipment and path protection, including Ring (Loop) protection. It has to support ATPC, RTPC, and reverse channel switching. It has to have built-in tributary add drop and cross-connect functionality. It has to have in-service performance monitoring and built-in self diagnostic tools to distinguish equipment failures from path failures. It has to provide secured network management systems with various security levels etc.

4. RF PARAMETERS REQUIREMENTS

High-level modulated signals require high signal-to-noise ratio (C/N) to maintain better than 1.0 $\times 10^{-12}$ residual bit error rate (RBER).To meet this RBER requirement, good linearity, good phase noise, good amplitude response, and good group delay etc. are required. Without the powerful signal processing techniques, the requirements for these parameters would have to be very stringent, which could be expensive and difficult to manufacture.

Powerful Forward Error Correction (FEC) schemes and powerful adaptive slope and time domain equalizers are implemented to relax these RF parameters. Depending on the spectrum efficiency requirement and the regulatory spectrum mask constraints, this scalable radio will automatically choose the appropriate modulation with appropriate FEC schemes to provide maximum system gain. The FEC is programmable to be Reed Solomon with programmable correctable bytes T, RS (T), or 2D or 4D Trellis Code Modulation (TCM) concatenated with RS (T). An interleaver in conjunction with RS (T) will further enhance the system robustness. 2D TCM and 4D TCM have very high coding gain. However, they are not good for correcting burst errors. Reed Solomon FEC can have high coding gain also, and is very good for correcting burst errors, especially in conjunction with the interleaver. Since the ODU can be installed in very harsh outdoor environments, whenever TCM is implemented with this scalable radio, it is always concatenated with RS (T) with interleaver.

With powerful FEC, the transmit power amplifier (PA) can have less back-off comparing to that with lesser FEC. In most cases, the regulatory transmit spectrum mask is likely to be the limitation on how far the PA can be driven for any given modulation level.

To be able to use the same hardware to meet standard frequency plans and most odd frequency plans, transmitter carrier frequency and receiver carrier frequency are independently programmable. The frequency step size as low as 5 KHz or lower in certain frequency bands is implemented. These synthesizers have wide tuning ranges. Synthesizer with small frequency step sizes generates more in-band spurious which requires a narrower loop bandwidth to achieve a good close-in phase noise. On the other hand, narrower loop bandwidth tends to be less robust against vibrations and phase hits. Low cost L.O. synthesizer design is particularly challenging when the signal symbol rate is low, such as in the case of 16 T1 in 5 MHz channel separation with 128 QAM.

5. CARRIER RECOVERY LOOP OPTIMIZATION

The close-in carrier phase noise is being attenuated by the demodulator carrier recovery phase-locked loop, whose transfer function is a second order high pass as shown in Figure 3.

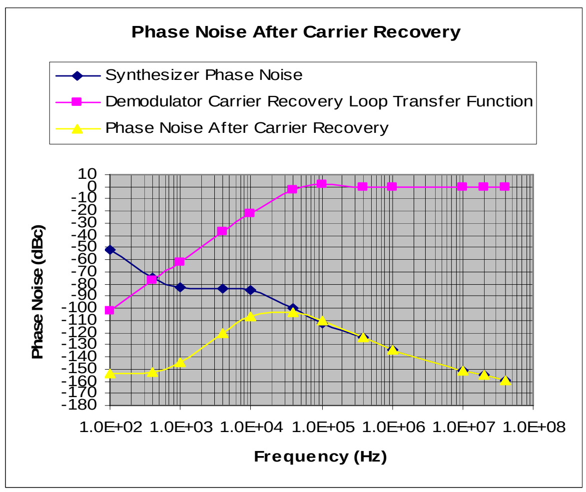

Figure 3: Recovered Carrier Phase Noise

Typically, demodulator carrier recovery loop bandwidth is between 0.5% and 2% of the symbol rate. Wider carrier recovery loop bandwidths can track wider close-in phase noises and larger instantaneous phase shifts. As a result, it will reduce the overall integrated phase noise when the incoming signal C/N ratio is relatively high.

Figure 4 shows the C/N of the recovered signal as a function of the carrier recovery loop bandwidth. In this particular test, the modulated signal is a 128 QAM signal with 3.9 Mbaud symbol rate (16 T1 in 5 MHz channel spacing). The carrier is phase-modulated with a 10 KHz tone resulting in 5 degree close-in phase noise, and no external Additive White Gaussian Noise (AWGN) is added to the modulated signal.

The test result shows that when the carrier recovery loop bandwidth is set to 20 KHz (0.5% of the symbol rate), the C/N of the demodulated signal is 33.2dB. When the loop bandwidth is increased to 40 KHz (1% of the symbol rate), the C/N is improved to 34.5 dB. When the loop bandwidth is further increased to 80 KHz (2% of the symbol rate), the C/N is further improved to 35.7 dB. This is due to the fact that the close-in carrier phase noise is attenuated by the carrier recovery PLL, and the integrated phase noise of the recovered carrier is reduced with the wider carrier recovery loop bandwidth, if the noise level of the modulated signal is relatively low.

The constellation of the recovered signal with carrier recovery loop bandwidth of 80 KHz (2% of the symbol rate) is shown in Figure 5.

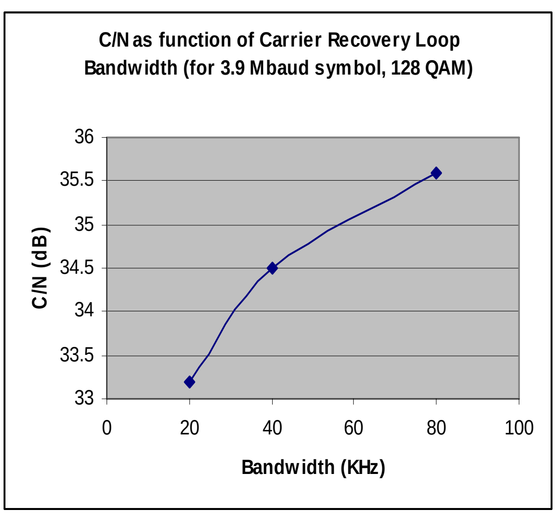

Figure 4: C/N as a function of Carrier Recovery Loop Bandwidth

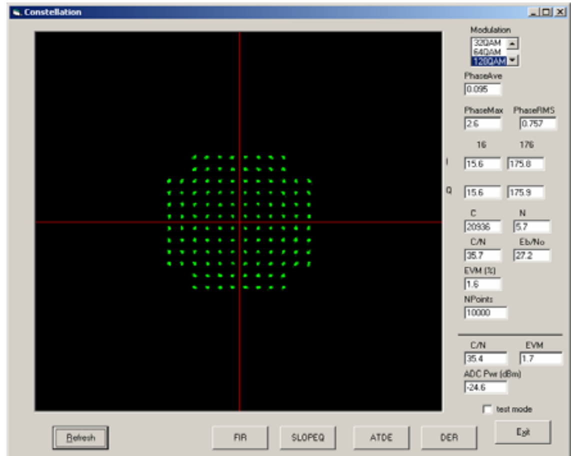

Figure 5: Constellation of the 3.9 Mbaud 128 QAM demodulated signal

When the demodulator carrier recovery loop bandwidth is wider, the loop gain is increased accordingly, and output phase noise is increased. If the loop bandwidth is too large, it will eventually degrade the receiver BER threshold.

Figure 6 shows the BER curves as a function of carrier recovery loop bandwidth for the same 16 T1/128 QAM system test with FEC disabled and with good carrier phase noise (phase modulation with 10 KHz tone is disabled).The BER curves for carrier recovery loop bandwidth of 0.5% (20 KHz) and 1% (40 KHz) of the symbol rate are more or less the same. However, when the bandwidth is increased to 2% (80 KHz), the BER threshold @ 1.0E-5 is degraded by approximately 0.5 dB, compared to that with a loop bandwidth of 1% of the symbol rate.

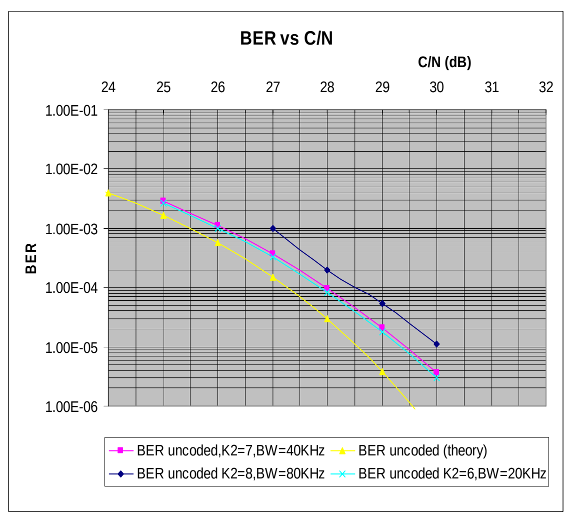

Figure 6: BER curves of 3.9 Mbaud/128 QAM as a function of the carrier recovery loop bandwidth

When the carrier recovery loop bandwidth is excessive, the degradation of the BER threshold for a system implementing high FEC coding gain is worse; since the noise level of the signal with higher coding gain is higher than that with lesser FEC coding gain for any given BER.

The carrier recovery loop bandwidth will also determine the carrier acquisition time. The larger the bandwidth, the faster the carrier recovery will be. The carrier recovery time of the signal with higher symbol rate is usually shorter than that of signal with low symbol rate. Thus, the carrier recovery loop bandwidth has to be optimized based on the real system.

6. ADAPTIVE EQUALIZER

Without costly tuning and/or components selection during manufacturing, it is difficult to have good in-band amplitude response and group delay, which would be required for high-level modulation signals if there were no built-in equalizers.

This scalable radio implements an adaptive time domain equalizer and an adaptive frequency domain slope equalizer, which can mitigate some of the RF imperfections. Moreover, these equalizers are used to mitigate signal distortion during multi-path fading. In path-protected (Frequency Diversity or Space Diversity) system configurations, these equalizers in conjunction with a well designed receiver switching circuit and a good anticipatory switching algorithm will ensure errorless receiver switching during selective fading occurrence.

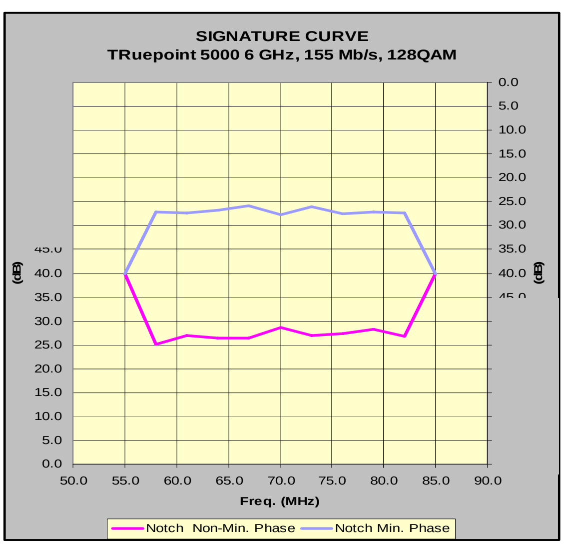

Figure 7: Typical two-rays delay Signature Curves of 6GHz radios for 155 Mb/128 QAM @1.0 E-4

The implemented adaptive time domain equalizer has 21 feed forward taps. Figure 7 shows the typical signature curves of 6 GHz radios for 155 Mb/128 QAM systems with 6.3 ns two-ray delay.

7. LATENCY CONSIDERATION

In many applications, large signal latency over a radio link is undesirable. The data latency over a radio link is contributed by the free space propagation delay and the equipment delay. The free space propagation delay is 3.33 µs/km. The radio delay is generated mainly due to data buffering while processing them such as multiplexing and de-multiplexing, signal mapping, FEC coding and decoding etc. However, a large portion of the delay is contributed by RS FEC encoding/decoding, especially when interleaver is also implemented. The lower the aggregate payload over the air link, the higher its latency will be.

For Ethernet data transmission, there is a processing related latency in addition to the radio latency described above. This latency is generated in the built-in Ethernet switch of the radio and the Ethernet data mapping over the multiplexer frame. The latency depends also on the Ethernet port interface rate, i.e. 10BASE-T or 100BASE-T or Gigabit Ethernet, the Ethernet frame size, and the allocated air link capacity to this Ethernet data. The Ethernet data latency increases with increasing Ethernet frame size, with lower air link capacity assigned to this Ethernet data, and with the lower Ethernet interface rate.

Figure 8 shows Ethernet data latency over a link of TRuepoint® 5000 radios. In this case, the radio is configured to carry combined TDM and Ethernet data equivalent to 75 E1 or 100 T1 (155 Mb/s) airlink capacity, and 50 E1 or 65 T1 (approximately 100 Mb/s) are assigned to carry data from one of the 100BASE-T Ethernet ports. The signal is modulated with 4D 128TCM concatenated with Reed Solomon code, with symbol rate around 25 Mbaud. The end-to-end 100 Mb/s Ethernet data over one hop is 248 µs for 64 bytes Ethernet frame and 596 µs for 1518 bytes frame. In this case, 230 µs latency is contributed by latency due to FEC encoding/decoding, interleaver/de-interleaver, and other radio signal processing. The additional time over 230 µs is contributed by the Ethernet data processing in the radios. The larger the Ethernet frame size, the larger the Ethernet data latency will be.

In applications with Transmission Control Protocol (TCP), where acknowledgement is required, excessive latency can drastically reduce the data throughput.

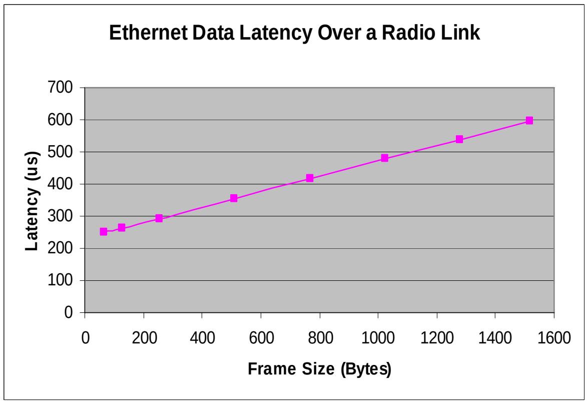

Figure 8: Ethernet Data Latency as Function of Ethernet Frame Size

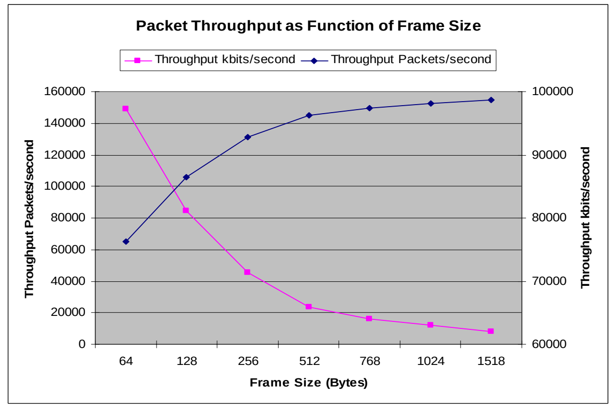

Figure 9: Ethernet Data Throughput as a Function of Ethernet Frame Size

8. MIXED TDM AND ETHERNET DATA IMPLEMENTATION

There is increasing demand for a radio that can simultaneously carry TDM and Ethernet data.

There are several encapsulation techniques and standards defining mapping Ethernet frames over SDH/SONET links such as Virtual Concatenation (VC), Link Capacity Adjustment Scheme (LCAS), Link Access Procedure-SDH (LAPS), and Generic Framing Procedure (GFP).

With a proprietary multiplexing frame and encapsulation implemented in this scalable radio, up to 16 E1/T1 TDM data and Ethernet data from several Ethernet ports can be programmed to generate payload between 4 Mb/s (equivalent to 2E1) and 180 Mb/s (equivalent to 116 T1) to be transmitted over the radio links. The maximum E1/T1 tributary number is limited to 16 due to space constraint. Any of the TDM data time slots can be assigned to the Ethernet data. When the combined TDM and Ethernet data capacity exceeds 16E1/T1 equivalent rate, additional time slots are added to accommodate the additional Ethernet data capacity in the same framing format.

The Ethernet data payload throughput efficiency over the radios is dependent on how much overheads are in the radio multiplexer frame. It also depends on the Ethernet frame size itself. The Ethernet data throughput over the airlink increases with the Ethernet data frame size as shown in Figure 9. This is due to the fact that each Ethernet frame has fixed overhead bytes, i.e., 6 bytes Destination Address, 6 bytes Source Address, 2 bytes Length/Type, and 4 bytes Frame Check Sequence (FCS). In addition, there are 7 bytes Preamble, one byte Start Frame Delimiter (SFD), and 12 or more Inter-Frame Gap (IFG) bytes transmitted with each Ethernet Frame.

Figure 9 shows the measured Ethernet data throughput with proprietary framing and encapsulation scheme implemented in TRuepoint® 5000 radios. In this test, the radios are configured to carry 155 Mb/s airlink capacities with 128 QAM. Out of this 155 Mb total airlink capacity, 100 Mb/s (equivalent to 50 E1 or 65 T1) is assigned to carry Ethernet data. For a frame size of 64 bytes, up to 148810 packets per second (76.190 Mbit/s) can be transmitted over the airlink, and with a frame size of 1518 bytes, up to 8127 packets per second (98.7 Mbit/s) Ethernet data can be transmitted over the airlink without dropping any packet. The stated frame size in Figure 9 includes Destination Address bytes, Source Address bytes, Length/Type bytes, and FCS bytes and MAC client data. It doesn't include Preamble, SFD and IFG bytes.

7. CONCLUSION

System design considerations for a universal, programmable, scalable PDH/SDH (SONET)/Packet data point-to-point radio platform has been presented. With implementation of state-of-the-art DSP technology, some RF parameters specifications can be relaxed. Some of the requirements and design trade-offs such as system robustness vs. data latency, choice of carrier recovery loop bandwidth have been discussed. TRuepoint® 5000 radio incorporates a wide band RF technology with flexible frequency setting and state of the art DSP technology. It enables the same radio to be programmed to carry data from 4 Mb/s to 180 Mb/s with QPSK to 256 QAM to meet all spectrum efficiency requirements in all standard channel plans, with channel separation between 2.5 MHz and 56 MHz.

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