Design of a hybrid switching architecture for avionic WDM platforms*

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A novel hybrid switching architecture using optical circuit switching for intra-subnet communication and fiber channel (FC) for inter-subnet communication is proposed. The proposed scheme utilizes small-size arrayed waveguide grating routers (AWGRs) and legacy FC switches to construct the large-scale avionic network, thus has the potential of the lower latency, the satisfactory network bandwidth and the lower power consumption. The simulation results verify that the proposed architecture outperforms FC switched architecture in terms of real time performance and power consumption.
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Fiber channel (FC) as a high-speed networking technology has been deployed on a number of military/aerospace platforms[1]. Owing to the incomparable performance of wavelength division multiplexing (WDM), i.e., high capacity, light weight and data transparency, the advanced optical networks with WDM have been targeted as the technology to realize the desired avionic network in the future[2].

Avionic mission-critical applications require connectivity among source/destination pairs with high bandwidth (more than gigabits per second), high degree of connectivity and low latency (commonly in microseconds range)[3]. Neither optical switching nor optical multiple access techniques can simultaneously meet all of these requirements. As a result, such applications will be based on a combination of optical technologies and electronic packet switching technologies, such as FC[3,4]. Due to the status of optical switching technology, the wavelength routing combined with electrical switching is one of the best solutions to solve the problem of in-flight connectivity up to now[5].

The various avionic subsystems have various requirements for services, which can generate a wide range of traffic patterns and a data rate ranging from kilobits per second to gigabits per second[6]. Based on the traffic characteristics of avionic application, subnet partition is used to divide the numerous end nodes into different domains, as depicted in Fig.1. End nodes communicate with each other at high traffic volume, which are divided into the same subnets, and can identify the subset of traffic best suitable to optical circuit switching.

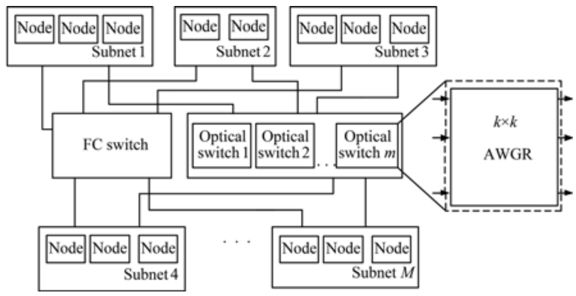

Fig.1 Schematic diagram of the proposed hybrid switching architecture

Based on subnet partition, a hybrid switching architecture consisting of traditional FC electronic switching components and a number of higher bandwidth optical components is proposed as shown in Fig.1. Arrayed waveguide grating (AWG)-based optical circuit switches are used for intra-subnet communication, while a legacy FC network (electronic packet switching) is used for inter-subnet communication. In our proposed architecture, the high-speed optical switching fabric can be constructed from a set of low port-count arrayed waveguide grating routers (AWGRs), which avoids the large crosstalk noise due to the narrow wavelength channel spacing[7]. Low-cost electrical switching is used for the inter-subnet communication to support the increased demand of interconnectivity (all-to-all communication in different subnets) at reduced traffic volume. For realizing the above-mentioned switching fabric topology, small-size AWGRs and legacy FC switches are utilized[8], so that the cost and power consumption are reduced. Meanwhile, this proposed ar-

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chitecture provides a solution to update network for future capability without destroying the existing FC structure.

The network and node design of this architecture are illustrated with an example of *N* terminal nodes across *M* subsystems, and each subnet accommodates *k* terminal nodes at most, as shown in Fig.2.

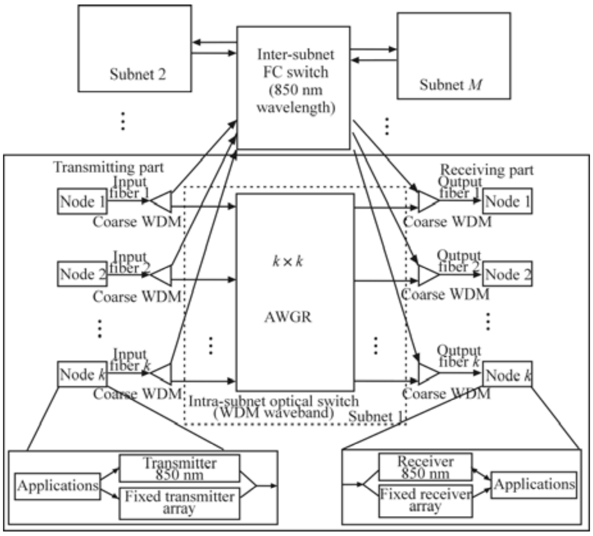

Fig.2 Network and node architecture of the hybrid switching architecture

The connection of proposed scheme is shown in Fig.2. A 1×2 coarse wavelength division multiplexer/demultiplexer (mux/demux) is attached to each terminal node. Each of *N* terminal nodes is connected to a fabric-port (F_port) of the FC switches via one branch of mux/demux, while each of *k* terminal nodes in the same subnet is connected to one port of the *k*×*k* AWGR via another branch of mux/demux by two fibers, one for transmission and one for reception. The fibers can use low-cost multi-mode fibers, since the maximum distance in the avionic network is no more than a few hundred meters. The structure of the proposed optical switch is shown in the dashed box of Fig.2.

In this case, each terminal node is equipped with an 850 nm transceiver for inter-subnet communication and an additional array of fixed-tuned transceivers that support *k* wavelengths within one free spectral range (FSR) in 1310 nm or 1550 nm wavelength window as WDM waveband for intra-subnet communication, respectively. With the development of optical elements, *k* fixed-wavelength transceivers may be replaced by a few tunable wavelength transceivers, so the number of transceivers equipped for each processor can be significantly reduced. The AWG's attractive property of spatial wavelength reuse[9], in combination with fixed-tuned or tunable transceivers in the end nodes, enables traffic transmission concurrently. In turn, this makes it possible to support heterogeneous traffic with high bandwidth and strict real-time constraints in avionic network. Meanwhile, the AWGRs and coarse wavelength division multiplexer as passive optical components can provide high reliability and low cost.

We compare the proposed hybrid switching architecture with a reference FC electronic packet-switched architecture in terms of real time performance and power consumption. The traditional FC switched network as reference consists of 56 FIC ports and 2 32-port switches including 28 F_Ports and 4 expansion ports (E_Ports). 56 FIC ports are connected to 56 F_Ports of 2 switches, while 4 E_Ports of one switch are connected to 4 E_Ports of another switch. In our proposed scheme, 56 terminal nodes are equally divided into 8 groups for simplicity (subnet partition method will be considered later), and connection relation is described in Fig.2.

The traffic in avionic network consists of a mixture of applications, and the percentage of the traffic in the same subnet depends on the applications in the terminal nodes. So we examine the real time performance and power consumption for three different traffic mixtures with the ratios of intra-subnet to inter-subnet communication of 20%/80%, 50%/50% and 80%/20%, respectively.

The real time performance is one of the critical measures for avionics network, and the end-to-end (E_T_E) delay boundaries under two network architectures are analyzed based on deterministic network calculus theory.

Because of the deterministic communications in avionic network, it is possible to statically define all the flows in the network. We consider that all the flows have identical characteristics with sending period of 4000 μs and burst length of 4000 bits. The FC switch works at 100 Mbit/s, and its technological latency is 16 μs. Due to static light path configuration, the delay of intra-subnet communication is assumed as 20 μs.

There are 120 messages with 50%/50% traffic mixtures in the network, and an upper boundary for E_T_E delay of each message is shown in Fig.3. Compared with the conventional design, the E_T_E maximum delay of each message is clearly improved, especially for intra-subnet messages (20 μs). From Fig.4, the average maximum delays of these two architectures are both decreased as the ratio of intra-subnet to inter-subnet traffic increases, since the message across the two FC switches is greatly reduced due to the message distribution. It is obvious that as the percentage of intra-subnet traffic increases, the average network delay of the hybrid switching architecture is much less than that of the corresponding FC switched network.

The researches in Ref.[10] confirm that the power consumption of the switching infrastructure is larger than that of the transport infrastructure. So we only measure the power dissipated for the switch plane.

The two network architectures considered here are capable of providing each terminal node's total bandwidth at 10 Gbit/s with average link utilization about 50% in the following study. In FC switching fabric, 850 nm small form-factor pluggable plus (SFP+) transceivers are deployed for each terminal node and corresponding F-port. Under the proposed hybrid switching scheme, each node is equipped with a 6×1 photonic integrated transceiver array at gigabits per second (or a tunable transceiver above 6 Gbit/s) and an 850 nm small form-factor pluggable (SFP) transceiver at 4 Gbit/s to give each terminal node equivalent bandwidth.

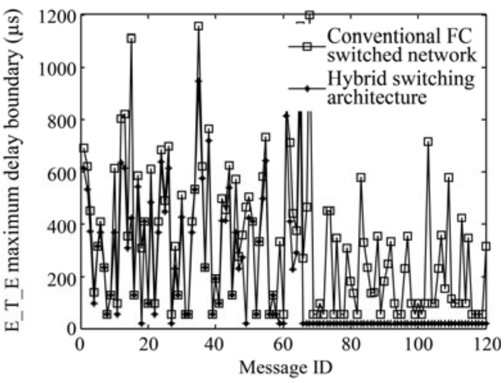

Fig.3 E_T_E delay boundaries of conventional FC switched network and the proposed hybrid switching architecture

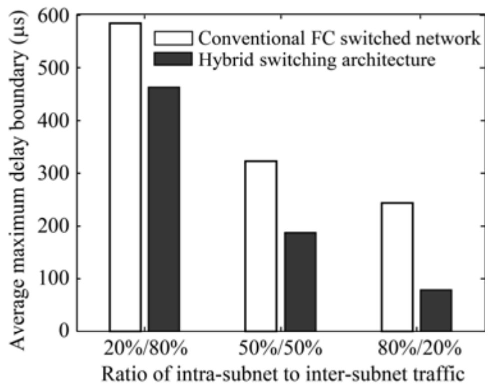

Fig.4 Average delay boundaries with different ratios of intra-subnet to inter-subnet traffic in conventional FC switched network and the proposed hybrid switching architecture

The power consumption comparison is obtained based on the estimations of the state-of-art device performance studied in Refs.[11-14]. For the FC switches, the power consumption is around 1 W for 1 Gbit/s from the power analyses in Refs.[12] and [13]. We summarize the power consumption parameters of optical transceiver in Tab.1.

Tab.1 Power consumption parameters of optical transceiver

	SFP			SFP+	Transceiver array	Tunable XFP
Rate (Gbit/s)	1	2	4	10	1	10
Power (W)	0.5	0.75	1	1.5	0.5	2.5

For avionic network with traditional FC switching fabric and our proposed scheme using 56 interconnected terminal nodes, the overall power consumption can be expressed as

$$P_{\text{FC\_switch}}=\sum_{N_{\text{d}}}P_{\text{Transceiver}}+\sum_{N_{\text{FC\_sw}}}\left(P_{\text{FC\_SW}}+\sum_{N_{\text{p}}}P_{\text{SW\_port}}\right),\qquad(1)$$

$$P_{\text{novel}}=P_{\text{Optical\_switch}}+P_{\text{FC\_switch}}=$$
$$\sum_{N_{\text{d}}}P_{\text{TRx\_array}}+\left[\sum_{N_{\text{d}}}P'_{\text{Transceiver}}+\sum_{N_{\text{FC\_sw}}}\left(P'_{\text{FC\_SW}}+\sum_{N_{\text{p}}}P'_{\text{SW\_port}}\right)\right],\qquad(2)$$

$$P'_{\text{novel}}=P_{\text{Optical\_switch}}+P_{\text{FC\_switch}}=\sum_{N_{\text{d}}}P_{\text{Tunable\_TRx}}+$$
$$\left[\sum_{N_{\text{d}}}P'_{\text{Transceiver}}+\sum_{N_{\text{FC\_sw}}}\left(P'_{\text{FC\_SW}}+\sum_{N_{\text{p}}}P'_{\text{SW\_port}}\right)\right],\qquad(3)$$

where N_{d} is the number of terminal nodes, $N_{\text{FC\_SW}}$ is the number of FC switches, N_{p} is the port number per FC switch, $P_{\text{Transceiver}}$ is the power of the 850 nm transceiver of each terminal node, $P_{\text{FC\_SW}}$ is the power of each FC switch, $P_{\text{SW\_port}}$ is the power of the optical transceiver module of each FC switch port, $P_{\text{TR}x\text{\_array}}$ is the power of the fixed-tuned transceiver array of each terminal node, and $P_{\text{Tunable\_TR}x}$ is the power of the tunable transceiver of each terminal node.

Fig.5 presents the power consumption of the proposed scheme compared with the conventional design for different ratios of intra-subnet to inter-subnet traffic. For the conventional design, the total power consumption is independent of the traffic ratio of intra-subnet to inter-subnet, because every packet must be routed by the FC switches. Instead, as the percentage of intra-subnet traffic increases, the power saving of the hybrid switch with WDM optical circuit switching and FC switches increases significantly, since the power dissipated in the FC electronic packet switches for these traffic flows is eliminated. Therefore, the proposed scheme consumes the decreasing energy as the percentage of intra-subnet traffic increases. Hybrid switch delivers the similar results when either 6 fixed transceivers or 1 tunable transceiver is deployed for terminal nodes in intra-subnet communication. When the percentage of intra-subnet traffic reaches 80%, the hybrid switch with 6 fixed transceivers can provide reduction up to 25% in the total power consumption as shown in Fig.5. Also, the power consumption of the hybrid switch with 6 fixed transceivers equals that of the FC electronic switch when the ratio of intra/inter traffic is 38/62, where the additional power consumption from the optical WDM transceiver arrays is canceled with the power dissipated in the FC switches for the inter-subnet traffic. Furthermore, it is evident that the power consumption of hybrid switch with tunable transceiver is less than that with transceiver arrays as shown in Fig.5, since the tunable transceiver for the intra-subnet traffic consumes less power than transceiver arrays, and the power dissipated in the FC switches for the inter-subnet traffic remains unchanged. By using the tunable transceiver, 6% power reduction can be achieved for the same ratio of intra/inter traffic.

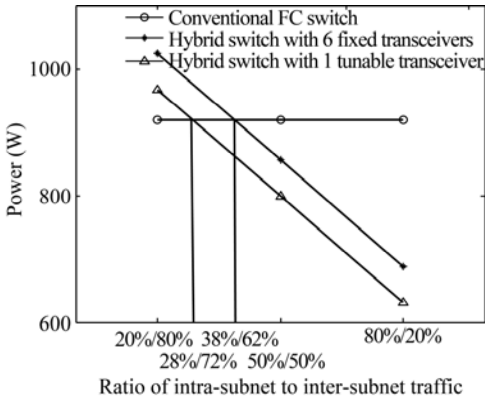

Fig.5 Power consumption of different switching architectures

Based on subnet partition, we present a hybrid optical/electrical architecture to enable new bandwidth intensive application. According to this proposed scheme, single-wavelength FC network can be seamlessly upgraded to multi-wavelength WDM local area network. Simulation results show that the use of simple optical components improves the real time performance of the system and reduces the overall power consumption.

References

[1] Mike Glass, High-Speed 1760 and FC-AE-1553 Pave Upgrade Path for 1553, The Journal of Military Electronics & Computing, 1 (2009).

[2] Reardon C., Profumo J. and George A. D., Comparative Simulative Analysis of WDM LANs for Avionics Platforms, Military Communications Conference (MILCOM), 1 (2006).

[3] Haim Kobrinski, DWDM Networking Technologies for Avionics Applications, Avionics, Fiber-Optics and Photonics Technology Conference (AVFOP), 1 (2008).

[4] Michael M. Salour, A WDM Optical Network for Avionics, Avionics, Fiber-Optics and Photonics Technology Conference (AVFOP), 13 (2005).

[5] Masanovic M. L., Barton J. S., Parker J. and Nicholes S., Photonic Integrated Circuits for Optical Routing and Switching Applications, Optical Fiber Communication and National Fiber Optic Engineers Conference (OFC/NFOEC), 1 (2011).

[6] Kumar A., Sivakumar M., Wang D. and McNair J. Y., Effect of Traffic Patterns on Optical Time-Division-Multiplexed/WDM Networks for Avionics, Avionics, Fiber-Optics and Photonics Technology Conference (AVFOP), 73 (2008).

[7] In-Sung Joe and Olav Solgaard, Scalable Optical Switch Fabric for Avionic Networks, Avionics, Fiber-Optics and Photonics Technology Conference (AVFOP), 1 (2005).

[8] Jane M. Simmons, Journal of Lightwave Technology **25**, 3658 (2007).

[9] Yao Qiong-bo, Liu Feng-qing and Feng Han-lin, Journal of Optoelectronics·Laser **23**, 501 (2012). (in Chinese)

[10] Rodney S. Tucker, IEEE Journal of Selected Topics in Quantum Electronics **17**, 261 (2011).

[11] Baliga J., Ayre R., Hinton K., Sorin W. V. and Tucker R. S., Journal of Lightwave Technology **27**, 2391 (2009).

[12] Nathan Farrington, Erik Rubow and Amin Vahdat, Data Center Switch Architecture in the Age of Merchant Silicon, 17th IEEE Symposium on High Performance Interconnects, 93 (2009).

[13] Grobe K., Roppelt M., Autenrieth A., Elbers J.-P. and Eiselt M., Communications Magazine **49**, 25 (2011).

[14] Abdul Latif, YU Chong-xiu, XIN Xiang-jun, Aftab Husain, Ashiq Hussain, Abid Munir and Yousaf Khan, Optoelectronics Letters **8**, 372 (2012).