Critical National Need Idea

Transformative Integrated Access Network (TIAN) For Revolutionizing The Internet

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Vision

In the last 40 years, the US has led the development of the core technologies behind the current computing revolution. Starting with discrete electronic components, this transformation was enabled by massive integration through micro- and nano-technologies to provide cost-effective high-speed computing. Ultra-high-speed telecommunication technology, which is fueled by optical technologies, has not followed this trend. High-density integrated optoelectronics is not currently affordable for widespread access network applications. Although everyone can have GHz computers on their desk, their communication access speeds in the United States tend to be Mbit/s, at best. With the advent of high-speed, high-density access networks (i.e., Fiber to the home, 3G/4G cellular, Wi-Max, etc.), available bandwidth at the edge of the network will need to grow dramatically, and thus require that the aggregated access capacity be comparable to what is now available in the network core. Over a fifteen year horizon, keeping the US in a leadership position in information technologies will require developing dense, integrated optoelectronic systems with the capabilities of the current optoelectronic network core at the cost of the current electronic access network. In analogy to how the supercomputer of 40 years ago became the laptop of today using massive integration of discrete components, our vision is ***to create the "PC" equivalent of the optical access network.*** We will accomplish this by transforming the costly discrete optoelectronic technologies of today's network into affordable, highly integrated optoelectronic subsystems to demonstrate novel optical network functionalities and infrastructure that enable heterogeneous services. Our ultimate goal is to provide the technological foundation for an advanced optical access network that simultaneously achieves efficient high data rate aggregation, to amortize the cost for end users, while providing the necessary flexibility to support diverse end user requirements. The development of these technologies is essential for delivery of single user data rates approaching 10 Gb/s and the associated services to a broad population base regardless of the "last-mile" technology. This vision will enable affordable, flexible access to any type of service to anybody, anywhere, at anytime and motivates the formation of the *Center for Integrated Access Networks* (TIAN).

The intellectual merit of TIAN and its mission is to create transformative technologies for optical access networks where virtually any application (e.g., multimedia streaming, data intensive web applications) requiring any resource can be seamlessly and efficiently aggregated and interfaced with existing and future core networks in a cost effective manner.

The University of Arizona and its partner institutions, the University of California at San Diego, the California Institute of Technology, Stanford University, the University of Southern California, University of California at Los Angeles, University of California at Berkeley, Columbia University, Norfolk State University and Tuskegee University, will establish TIAN.

Motivation and Rational

There are two dominant trends in modern networking. The first is the push to meet demands by providing continuous increases in the raw data rates while driving a nearly exponential reduction in the cost of transporting each bit. The second trend is the growing diversity in the myriad of heterogeneous applications and services that must be supported by the network in terms of bandwidth, latency, security, and reliability. In various forms, these trends conflict in the core, access, and local networks. The historical trend of the existing core network has been to build a high performance physical layer based on discrete optoelectronic technologies that drive down the cost of data transport through standardization and a large amortization base. The core provides services through a variety of protocols or overlay networks. The trends for current local access networks are quite the opposite, with each service provider (cable, landline phone, cell phone, etc.) optimizing their network independently using a multitude of heterogeneous technologies, widely varying physical network interfaces, and different business cost models. When these local and/or access networks are interfaced to the core, the requirements for capacity, latency, security, and reliability must be ensured, thus creating the tremendous core/access bottlenecks we face today and into the foreseeable future.

Current networks are largely predicated on the assumption that network bandwidth is so scarce that it must be finely multiplexed across multiple competing users. This design paradigm of scarce bandwidth makes it difficult to provide heterogeneous dedicated resources to any general-purpose network service. TIAN's principle mission is the direct migration of higher-layer functionalities onto integrated, low-cost, reconfigurable, optical technologies. This will enable the flexibility required by heterogeneous network services and eliminate the "scarce bandwidth" assumption by using the inherent high data rate qualities of optical systems, leading to a fundamental paradigm change for delivering high-speed access bandwidth to a scalable number of users. These functionalities and the associated infrastructure will be benchmarked in realistic settings using testbeds without the undue expense of constructing a complete network.

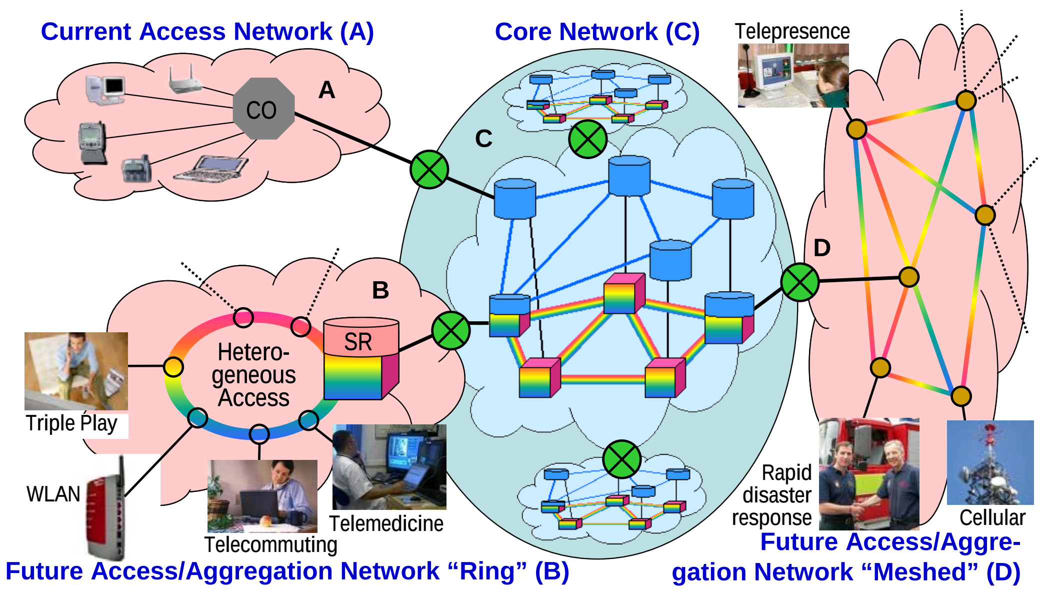

Fig. 1 *Illustrative networks: (A) existing star for access, (B) a potential form of the future optical access network consisting of a bi-directional WDM ring, (C) existing core network interfaced to the access networks via edge nodes, and (D) a second potential form of the future optical access network consisting of a mesh.*

Figure 1A displays one illustrative example (a star topology) of how an existing access network structure, where each customer (e.g. mobile service provider, internet service provider, cable TV provider, residential) is connected to a central office (CO) which is the only interface with the core network (C). The shortcomings of this canonical access network are: (1) it is cost prohibitive to move core technologies and employ their functionality in the access networks because the cost would be spread across too few users, (2) the high data rates that are already broadly available in the core do not extend to the access network and the associated customer sites due to these prohibitive costs; (3) the physical access lines are service specific and support limited bandwidth; new services would require major changes to the existing infrastructure. For example, if an access line in Fig. 1A has been designed for phone service, it will not support Gigabit Ethernet service. As an example, a desktop PC has nearly 40x more bandwidth available to it within the home wirelessly using 802.11n (~200 Mb/s) than the wireline connection to the outside (~ 5 Mb/s); (4) the existing access networks interfaces are completely opaque; different data rates, different protocols and different services simply cannot be forwarded seamlessly (i.e., transparently) from access to the core through the edge aggregation nodes.

Looking out over a fifteen year time horizon, the disconnect between the demand for increasing heterogeneity of local and access networks based on integrated technologies, the rigidity of the existing physical structure of the core based primarily on discrete optoelectronic technologies, and the current design methodology that assumes scarce bandwidth, defines the rationale and principle motivation for the Center for Integrated Access Networks (TIAN). ***The TIAN mission is to combine the high data rate handling capabilities of existing core networks with the flexibility of existing local and access networks to produce the technology to enable a transformative integrated high data rate access network that is both low-cost and highly flexible---the PC-equivalent for optical access networks.***

Figures 1B and 1D encompass our vision of the ubiquitous optical access network paradigm in which TIAN-researched disruptive photonic technologies enable new and existing applications/services with better quality (e.g. HDTV compared with regular TV) at lower cost to more people. We emphasize that rather than *dictating* a specific network, our approach of demonstrating novel network functionalities *enables* a multitude of diverse access network structures (e.g. bi-directional rings, mesh interconnects, etc.) that are seamlessly and transparently integrated with the core. Creating the seamless integrated system infrastructure to realize this vision drives TIAN’s collective efforts. Fig. 1B illustrates how in this transformative network, an aggregation switch router (SR) inserted in the central office collects all types of traffic from many access points, grooms them and directs them via edge nodes into the core. A meshed access/aggregation network (Fig. 1D) co-exists within our integrated access vision delivering high-bandwidth transparent data paths through the core. The unique features of this integrated access network are: (a) the technologies developed for the core network such as multi-channel dense wavelength division multiplexing (DWDM) and reconfigurable optical add-drop multiplexers (ROADM) are directly transferred and adapted to the access network by effective cost scaling using novel, integrated photonics; and (b) the development of transparent and flexible input/output (I/O) interfaces, such as wireless, photonic, and RF-to-photonics for handling heterogeneous information at the access points.

TIAN's new integrated system platform has the following advantages: (1) as the number of customers increase the cost per customer decreases since the cost is amortized over more customers for essentially the same infrastructure; (2) high data rates can be extended to the access network and the customer sites using proposed cost-effective integrated DWDM subsystems; (3) the limited bandwidth of existing access lines is increased by bringing the high bandwidth network "to the curb"; and (4) the technology enables the network to be flexible, transparent, and reconfigurable in order to support different data rates and services.

While the technology developed by TIAN will enable advanced optical access networks, this platform will be one of several options for static home/office users with wireless access clearly dominating for mobile users. The complete network will likely be a mix of options. An important conclusion of a workshop organized by our UCSD team with a number of wireless companies is that future high bandwidth wireless users will lead to a significant increase in the aggregate data rate (especially in densely populated areas), necessitating pushing the optical access network closer to mobile users. TIAN has a specific project targeted towards this requirement and we will continually monitor these future trends and incorporate the outcomes into our research.

The TIAN mission cannot be achieved by US industry alone because its current competitive economic environment makes it difficult to create the necessary highly integrated transformative opto-electronic technologies supporting ultra-high bandwidth access to a majority of the US population. Currently, these technologies are not being developed. As a partial consequence, our leadership position in broadband access has eroded: Over the past seven years, the US went from No. 4 in the number of broadband access connections per 100 inhabitants to No. 15! [*LA Times Nov. 28, 2007*]. A recent report issued in November 2007 states "findings indicate that although core fiber and switching/routing resources will scale nicely to support virtually any conceivable user demand, internet access infrastructure, specifically in North America, will likely cease to be adequate for supporting demand within the next three to five years. We estimate the financial investment required by access providers to bridge the gap between demand and capacity ranges from $42 billion to $55 billion, or roughly 60%-70% more than service providers currently plan to invest. It's important to stress that failing to make that investment will not cause the Internet to collapse. Instead, the primary impact of the lack of investment will be to throttle innovation-both the technical innovation that leads to increasingly newer and better applications, and the business innovation that relies on those technical innovations and applications to generate value. The next Google, YouTube, or Amazon might not arise, not because of a lack of demand, but due to an inability to fulfill that demand. Rather like osteoporosis, the under investment in infrastructure will painlessly and invisibly leach competitiveness out of the economy." [*"The Internet Singularity, Delayed: Why Limits in Internet Capacity Will Stifle Innovation on the Web," nemertes research, www.nemertes.com, Nov. 2007*]

A significant technological aspect of this issue lies in the fact that the current core and access networks are being optimized for very different criteria. In the core, the optimization is constrained by solutions that must fit within existing standards with technologies that have been developed during the last decade. On the access side, each local network must optimize for its own diverse input/output requirements and differing costs of services. *Adopting a green field approach on a fifteen year time scale not constrained by existing networks, TIAN will work across these traditional boundaries to cost effectively combine the current data handling capabilities of the existing core network with the diverse input/output requirements of existing access networks to create the technology that enables a nearly universal integrated access network that achieves our vision of the future integrated optical access network that can rapidly provide any service to anybody, anywhere, at any time.*

The broader impact of our research will be felt in every home and in our quality of life. It will improve educational opportunities, enhance distribution of medical services, avoid the expense and human costs of unnecessary commuting, minimize the environmental impact from infrastructure and pollution, substantially reduce our dependence on energy imports, increase our overall national security, and enable new and varied entertainment opportunities.

Strategic Plan

The TIAN strategic plan integrates three major elements: i) research thrusts with testbed activity, ii) industrial collaborations and technology transfer, and iii) education, outreach, and diversity. TIAN's vertically integrated research structure is designed to achieve our mission of creating fundamentally new integrated optoelectronic WDM subsystems for access network applications.

The existing network is typically divided into access, metropolitan (regional), and wide-area (or core/backbone), with optics being currently used mainly for optical point-to-point transport and electronics used mainly for routing and switching, especially at the aggregation points and interfaces between networks. These separations and the optimization at each level have been established independent of one another. In addition, in the case of the core network, the optimization is also independent of the specific services required. It is inefficient to build a separate network to accommodate each required service. Therefore, the future network will still be divided into heterogeneous access networks that interface to the core through edge nodes. These edge nodes aggregate data and map application-specific services into standard core protocols.

Maintaining and cost-effectively scaling the high data rates in the existing core with the required flexibility of access networks defines the two principle research focus areas of TIAN:

1) Transform expensive discrete components based subsystems into **flexible** cost-effective integrated optoelectronic subsystems to achieve **scaleable** and affordable high data rate access networks that are **transparent** to the core.
2) Demonstrate flexible network **functionalities** that provide **transparency** and **scalability** by moving services from the higher layers of the network closer to the physical layer. This requires cross-layer optimization. For example, TIAN will develop a multicasting (one-to-many) service, typically implemented with a software protocol, using a hardware –based nonlinear optical process at the physical layer in conjunction with cross-layer optimization. The result is a service that is more transparent to end-user applications.

These two focus areas have several common cross-cutting themes associated with each of the principle research topics: (1) the current mapping of application-specific services is not seamless (**transparency**), (2) the performance does not scale gracefully as traffic increases (**scalability**), and (3) the existing technologies cannot cost effectively meet the future requirements for flexibility (**functionality**).

i. Research organization:

The two research focus areas cut across the organization units of the program:

1) Optical Communication Systems and Networking will act as the "top-down" driver for the development and integration of components and devices that will enable integrated subsystems, co-optimized to cost-effectively provide high-data rate services to the "curb". It includes aggregation and access networks, cross-layer optimization, wavelength multicasting and ubiquitous monitoring. This thrust is the enabler and demonstrator of numerous new network applications including ultra high-bandwidth data centers and immersive tele-presence;
2) Subsystem Integration and Silicon Nanophotonics will explore signal conditioning, processing, reconfiguration, and control functions realized with various platforms including CMOS compatible nanostructures and silicon nanophotonics, and multifunctional integrated subsystems exploiting monolithic and heterogeneous integration.
3) Materials and Devices will act as the scientific and technological foundation by conducting research on new materials, device technologies, processing and integration methods for chip-scale integrated optoelectronics.

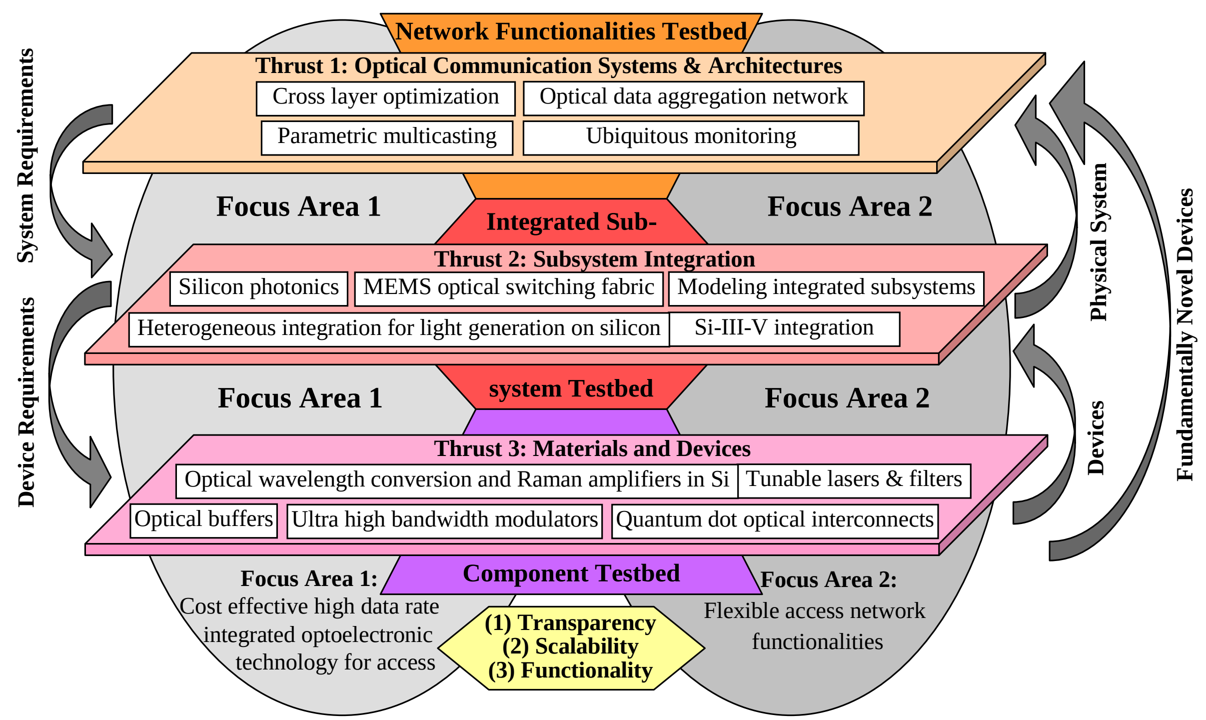

Fig. 2 *TIAN's* Research plan: two Focus Areas cutting across the three Research Layers with integrated Test beds and closed feedback loops for a systems driven approach

TIAN Testbed: The TIAN testbed is a shared research facility where TIAN's research efforts in diverse areas are combined, enabling effective collaborative research among participants and the wider research and industrial community. The testbed is a literal common ground where TIAN researchers and our outreach partners will meet and interact on the UCSD campus. In contrast to virtually any existing testbed, our goal is to work *across* network layers to assess how the migration of higher-level network functionalities into the optical physical layer impacts the design of flexible high capacity optical access networks. The ultimate goal of the testbed is to integrate the research in all three thrusts in order to demonstrate and quantify key enabling technologies. This provides the necessary hard data to determine the impact of TIAN's research without the expense of constructing a complete network. As TIAN progresses, this platform will evolve to incorporate more speculative technologies such as parametric optical signal processing, optical delay/buffer elements, and physical layer quantum security.

Well-defined metrics are essential to assess the impact of TIAN's proposed work and the success of our strategic plan. The initial metrics that TIAN will use are technology based. However, since a significant aspect of TIAN's success will rely on additional factors such as economics, rapidly changing social needs, and politics, we will seek additional advice from our Strategic Advisory Board, economists, social scientists and politiTIANs to more accurately assess and guide the overall strategic plan of TIAN. This complete set of metrics will be part of a "living document" which expands on the research plan in Fig. 2 to include more general top-down requirements (networks → systems → devices/components/materials), bottom-up enablers (vise versa), as well as impacts from/on customers/subscribers, service providers, and network operators.

ii. TIAN's Industrial Collaboration and Technology Transfer Program will be involved in all aspects of the TIAN: *strategic planning, supervision of and collaboration in research projects, operation of testbeds, mentoring of students and post-doctoral fellows, and education*. The goals of the Industrial Collaboration and Technology Transfer Program are to provide: (1) an industrial voice in the management of the Center, (2) industrial guidance in the selection and emphasis of research projects, (3) an avenue for technology transfer from the Center to industry, and (4) a path for industrial support of and participation in educational programs.

iii. TIAN's Education and Outreach will include: (1) educating a skilled and diverse workforce to lead the next-generation communications industry, (2) creating vertically integrated (from pre-college to post-graduate) curricula which are team-based, research-inspired and industry-oriented, (3) integrating engineering, technology and business education to stimulate technology transfer, and (4) promoting education to the broader community, K-12 students, teachers, under-represented minorities and the general public. Integral to the vision and mission of this approach is that *every researcher in the Center is actively involved in the education and outreach program of the Center*.

TIAN's Management Organization will be structured to: (1) select, focus, and direct research activities; (2) manage the TIAN's technical and other relationships among participants, with other institutions, and with the public; (3) plan, select, develop, and evaluate educational and outreach programs; and (4) enhance industrial membership, particularly for small companies; and (5) encourage and foster the development of intellectual property derived from TIAN's research with an ultimate goal to create new start-up companies and jobs. The overall goal for the Center will be *to achieve 50% participation in the leadership, faculty, and graduate/ undergraduate students categories from underrepresented groups*.