# Global Time for Overcoming Internet Challenges:
## Scalability with Guaranteed Performance

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**Abstract:** Scalability issues are emerging as central for the viability of the Internet continuous growth. During the next 10-15 years it is envisioned that the Internet will undergo several major transitions with respect to technologies, services and most importantly its size. Bandwidth demands are expected to grow up to 50-100 times; how can Internet support this demand growth? This project focuses on two critical problems: (1) cost (equipment and transmission) and (2) performance guarantees that are independent of the network size. Specifically, lowering the per-packet delivery cost to end-users, while providing real performance guarantees in order to ensure that end-users (all citizens) will be satisfied and be able to afford the service. In order to reduce cost our planned R&D activities will focus on two aspects of network scalability: (*i*) logical (e.g., addressing and routing) and (*ii*) physical (e.g., switching and scheduling). Intuitively, the scalability index is defined as the ratio between the factor of network growth (scalability factor) and the factor of cost increase; the larger the scalability index the better.

## 1. Scalability issues will dominate the future Internet continuous growth

It is envisioned that during the next 10-15 years, the Internet will undergo several major transitions with respect to technologies, services and most importantly its size. These transitions are led by the evolution of the Internet into a, what we call, global triple-any network. Namely, a global network – from anywhere to anywhere – that supports any service for anyone at anytime. Specifically, (*i*) anyone implies that users of all ages, financial statuses, and technical skills, will be able to access the network; (*ii*) any service implies that all contents with whatever encoding formats and bit rates will be accessible, irrespective of external (faults) or internal (congestion) impairments; while (*iii*) anytime implies "on-demand" service that for example is independent of predefined broadcasting schedule. We further think that the global triple-any concept may be implemented using the open access paradigm, which will allow any provider to participate in the data (content) supply chain, and consequently, satisfying the end-user desires.

Clearly, global triple-any is a wonderful proposition for the end-user, but can be very costly. The target of this proposal is to propose cost-effective technologies for the future Internet. We will, therefore, focus on the most scalable technologies for data packet delivery featuring: (*i*) low packet handling cost in the infrastructure (e.g., routing, switching), and (*ii*) predictable quality of delivery to users, with maximum efficiency (to maximize network resource utilization, thus minimizing the cost of the service). Clearly, reducing cost while ensuring premium quality of service is key for scaling the Internet.

## 2. Global time for optimal scalability and performance

One of the primary objectives of the European funded project **IP-FLOW** (**IP FL**ows over **O**ptical and **W**ireless – see, http://dit.unitn.it/ip-flow/) is to show how global time (or time-of-day) or UTC (coordinated universal time, a.k.a. Greenwich Mean Time – GMT), which is available from GPS/Galileo, can be used effectively to overcome some of the most difficult Internet challenges. Global time is the necessary condition for pipeline forwarding of packets. Pipeline forwarding is a known optimal method that is widely used in manufacturing and computing.

### *The pipeline forwarding paradigm*

> *"A pipeline is like an assembly line: Each step in the pipeline completes a part of the instruction. As in a car assembly line, the work to be done in an instruction is broken into smaller pieces, each of which takes a fraction of the time needed to complete the entire instruction."* ("Computer Architecture: A Quantitative Approach," by John L. Hennessy and David A. Patterson)

All computers now operate using pipelines, which are a simple extension of the automotive assembly line. The motivations for computer pipeline operation are optimal efficiency and speed (scalability). The computer lockstep or pipelining operation is predictable and assures that each individual datum is dealt with in a regular and timely manner. Prerequisite to pipelining in computers is the global time; the CPU clock dictates the processing progress for all data units. Pipeline forwarding in data networks requires global time, which is available today from the GPS and Galileo satellite constellations. GPS/Galileo satellites are capable of providing UTC (coordinated universal time), standard time, with 10s of nanoseconds accuracy.

Pipeline forwarding of packets across packet switched networks is achieved by using a switching method called Time-Driven Switching or TDS, which is a packet switching technology that uses time (of day, or UTC – coordinated universal time). Traditional packet switching technologies rely on asynchronous operation. Pipeline forwarding (with TDS) provides a service typical of circuit switched networks, i.e., a pipe between two points with deterministic service. But when it comes to implementation, pipeline forwarding is a *"best-of-breed"* solution compared to circuit switching and packet switching as it adopts simple elements and mechanisms from both, while not sharing the complex ones! For example, pipeline forwarding borrows low complexity time based routing from circuit switching (rather than the more complex address based routing of packet switching) and packet based multiplexing from packet switching (rather than the more complex byte-by-byte multiplexing of circuit switching).

However, since packet switching with pipeline forwarding differs from other existing—and currently widely deployed—technologies, the project will provide a novel architectural framework on how to deploy and utilize pipeline forwarding in the overall metro networking scenario. This has to be done by taking into account first (*i*) the current network infrastructure and practices in both operating the network and selling services to customers and then also (*ii*) the new opportunities, in both network operation and service creation, offered by pipeline forwarding. Specifically, the network cost to service providers (or operators) and predictable (deterministic) service guarantees provided to end-users. Consequently, solving a major scalability problem, namely, much larger network for much lower cost.