Abstract

Although the scope of Media Synchronisation is quite broad, a common thread relates to a sense of time and/or frequency as being a key enabler. The term ‘timing’ as applied in this paper, is used as an umbrella term that represents all aspects – whether time, frequency, or phase. In this paper, we firstly examine a range of multimedia scenarios where time and/or frequency synchronisation are used to facilitate better Quality of Service/Quality-of-Experience (QoS/QoE) for end-users - these scenarios include RealTime Communications (RTC) applications as well as Hybrid Broadcast/Broadband (HBB) applications. We then step back from the applications and examine the notion of Time-Awareness and its key role in Media Synchronisation. In particular we discuss the growing realisation of the importance of Time Awareness across the full end-to-end infrastructure over which Multimedia applications operate, and in this context, introduce the work of the recently formed Interest Group (IG) termed Time Aware Applications, Computers and Communications Systems (TAACCS). Although the scope of TAACCS extends to the so-called Internet of Everything (IoE), the Media Synchronisation community, though already acutely aware of timing issues, can learn a lot from its approach.

Author Keywords
Time-Awareness, Time, Frequency, QoS, QoE

ACM Classification Keywords
C.2.4 [Distributed Systems] Distributed application;
D.1.3 [Distributed Programming] Timing, control and synchronization;
H.5.3 [Group and Organization Interfaces] Synchronous interaction
Introduction

Over the last 15 years, a growing body of research has examined the need for, the challenges of achieving, and the opportunities relating to time and/or frequency synchronisation in packet based networks and applications. Time synch refers to the extent to which two or more entities agree on the Time-of-Day using a local timebase or a global standard such as UTC (Universal Coordinated Time). Frequency synch, also known as syntonisation, refers to the extent to which two or more entities operate at the same frequency. Over this timeframe, timing-related research undertaken at NUI Galway has focused on a range of multimedia related application types, summarised as follows:

- Opportunities for improving VoIP jitter buffer performance through implementation of synchronised time via the Network Time Protocol (NTP). This essentially optimises buffer playout delays based on the ITU-T recommendation on one-way delays for VoIP [1].
- Clock Skew detection and compensation for VoIP. This research developed a patented mechanism [2] for detecting skew via NTP/RTCP timestamps, so as to compensate for same whilst minimising QoS degradations [3].
- Improved synchronisation performance over WiFi. This research developed a patented synchronisation technique for WiFi that delivers synchronisation levels equivalent to those achievable over wired networks [4].
- Using the above synchronisation techniques over WiFi, further research developed the concept of an intelligent Access Point (iAP), that deploys a Software Defined Networking approach (SDN) to manage QoS/QoE across multiple concurrent RTC sessions. Essentially, the intelligent controller builds up knowledge of realtime delays for each RTC session, maps this to QoS scores, and dynamically alters MAC session parameters so as to prioritise certain RTC streams over others [5][6].
- Synchronising Hybrid Broadcast & Broadband Media streams (HBB). This research focuses on live or near-live streaming media, typically sports events. The application scenario implemented in a prototype represents a use-case where an end-user can select media streams that are logically and temporally related e.g. a video stream of a live football match, and a separate audio stream of the same football match from an Internet radio feed, and have them integrated into a single media stream. This research also examines the evolution of HTTP Adaptive Streaming (HAS), and the timing challenges and opportunities for near-live streaming. [7].

As the scope of synchronisation-related multimedia applications is quite broad, the accuracy of
synchronisation also varies significantly. For example, the audio/video synchronization accuracy requirements for live sports commentary scenario above are lower than that needed by conventional lip-synch for HD movies. In addition to the above HBB scenario, other applications of synchronisation include Inter-Destination Multimedia Synch (IDMS) and Inter-Device Synchronisation (IDES). For RTC applications such as VoIP, conferencing, and Gaming, synchronisation accuracy relating to QoS are usually in the low millisecond range. Details for broadcasting of Audio/Video are given in [8]. In [9] and [10], further aspects relating to media synchronisation are presented. The need for frequency synchronisation in multimedia relates to the fact that frequency offsets (or skew) result in cumulative time errors – usually manifested for multimedia applications in buffer overflow/underfill, and thus it also needs to be managed to help optimise QoS/QoE.

Generally speaking, synchronisation (time) is needed to measure latencies and to time-align media streams from separate sources as described in the scenario from [7]. Syntonisation (freq) is used to align producers of streams with consumers of streams so that the buffers on the producers and consumers can be optimally utilized without incurring overflow or underflows. To successfully achieve this, the network connecting the multimedia devices producing and consuming streams is also required to support a certain level of bandwidth guarantees (bounded latency) so that the data can be delivered in time, especially for delay sensitive applications. Synchronisation in this case thus gives you information about network delays which can be usefully used to tune jitter buffers. In summary, synchronisation and syntonisation of the producers and consumers by themselves is not enough to guarantee QoS and QoE. The network also needs to be time-aware to ensure the timeliness in delivery.

### Time Aware Applications, Computers and Communications Systems (TAACCS)

This Interest Group has recently published a NIST Technical Note [11] [http://dx.doi.org/10.6028/NIST.TN.1867], that takes an holistic view of Time Awareness – both in terms of where it stands today and where it needs to be in the future. The scope of the document is broad – it looks at Time Awareness in the context of the Internet of Everything (IoE) with predicted billions of interconnected devices. It examines the extent to which Time Awareness is present across the full end-to-end infrastructure over which IoE applications will run, identifies gaps between the state of the art (SOTA) and new requirements , and points in the direction of future required research to meet challenges and achieve expected IoE potential.

The key issue identified is that the IoE will require precise (and perhaps verifiable) timing in ways that current systems do not support. In terms of the end-to-end infrastructure, the common problem/challenge is that the design of applications, computers and communications systems has evolved such that it optimises data processing but in doing so, degrades timing accuracy. In practical terms, this results in applications, computers and networks that are designed for fairness and throughput rather than temporal determinism. As such, multi-core devices with complex pipelining and
cache prediction strategies, complex time sharing operating systems, and best effort/dynamic allocation networks with no admission control all represent significant advances when measured against metrics such as throughput, but cause problems for time and frequency. The paper acknowledges that solutions to some of these challenges have been achieved in niche sectors—especially in so-called hard Realtime Systems (RTS) found in critical infrastructure, but that the solutions are often hardware specific, sometimes proprietary, and are typically not scalable. TAACCS then identifies a range of topics where cross-disciplinary research is required so that Time Awareness can be achieved. These are:

- **Oscillators** – ultimately – the heart of a system’s timekeeping. The design usually requires a range of tradeoffs regarding performance, power and cost.
- **Time Transfer Systems** such as Network Time Protocol (NTP) and Precision Time Protocol (PTP) will need to deliver signals to an exponential increase in endpoints, with varying application-specific specifications of accuracy and integrity.
- **Time Aware Networks** will need development in a number of areas:
  - Network hardware and software will need new designs to both support and make use of time awareness. Significant progress has been made in this area under the umbrella term of Time Sensitive Networking (TSN), such as IEEE 802.1 TSN [12]. For example, 802.1AS is somewhat similar to the work previously highlighted in [4]. More generally, controlling latency in networks is crucial to many real-time applications within critical infrastructure. It is envisaged that much of the M2M (Machine-to-Machine) communications in the Internet of Things (IoT/IoE) will relate to critical infrastructure and thus time awareness will become increasingly important.
  - Network performance monitoring is required both for technical and financial reasons in the form of service-level agreements (SLA), and requires time synchronisation to varying degrees. For example, time synch of the order of milliseconds is required in financial trading and many RealTime Communications applications, though the timing requirements for financial trades are likely to increase to the microsecond range soon.
  - On a different level, precision timing facilitates better use of RF spectrum in networks.
- **Timing Support for Applications** will need cross-disciplinary research in the following areas:
  - Hardware and software support for predictable execution. This is a huge challenge for both as it goes against the recent design trends for throughput and abstraction.
  - Timing across interfaces will require standards and latency control especially when crossing network domains.
- **Development Environments (DE)** will need to evolve to support timing accuracy, independent of the hardware that systems are running on. This is a very big challenge and relates to the
notion that time needs to be built in as correctness criteria and that the development environment will work to that criteria, or at least let you know if criteria cannot be met.

- Innovative Time Aware Applications – the key message here is that as timing synchronisation becomes available to greater levels of precision, this can trigger a more innovative use of time, and will further stimulate the development of new application scenarios.

Finally, related work by [13] argues that whilst a lot of work has been done with regard to delivering precision timing to end devices, the availability and efficient use such of precision on the devices has not kept pace with such developments and much needs to be done to exploit this.

**TAACCS & Media Synch**

It goes without saying that the Media Synchronisation community are already acutely aware of time and frequency issues. The question then arises as to what insights can be gained from the work done by the TAACCS IG, which was established to address a more holistic view of timing across the IoE spectrum of applications. We argue that it is worthwhile considering the relevance of each of these challenges in the context of media synchronisation.

- Oscillators – A whole range of multimedia QoS problems are caused by frequency skew resulting from poor oscillators and/or poor compensating strategies. There is a drive to eliminate multiple oscillators on consumer-grade devices, largely to reduce power consumption. Such a move may help reduce skew impact.

- Time & Frequency Transfer Techniques. The growing use of time synchronisation for multimedia as detailed above, and the tighter precision with which it needs to deliver for multimedia can only be satisfied if the protocols meet the requirements. The performance of NTP is very much dependent on the underlying network as well as endpoint hardware and software. PTP implements endpoint timestamping at the MAC layer and thus eliminates much of the endpoint non determinism, found with NTP. However- though capable of delivering orders of magnitude better time synchronisation than NTP, it requires expensive and well managed networks with on-path support. Frequency distribution/transfer is a further key challenge for multimedia, especially when PLL/FLL approaches are used over packet based non deterministic networks. Synchronous Ethernet (SynchE) offers great potential in this regard but comes at significant financial cost. Combining PTP with SynchE is the ideal solution but cost prohibitive.

- Time Awareness in Networks & Cloud Infrastructure. As highlighted above, in the absence of precision timing sources such as GNSS, networks are often used to deliver
time and/or frequency to endpoints and thus time-awareness within the network can help with this process. Furthermore, networks need synch time to effectively monitor network performance – in a multimedia context, such monitoring can help control latency thus enforcing QoS requirements that are tied to a SLA. Software Defined Networking (SDN) and Network Function Virtualisation (NFV) are recent concepts that aim to improve certain network performance metrics through abstraction and centralised big-picture intelligence. Having precise time information can greatly enhance decision making for SDN and NFV.

Finally, time awareness challenges arising from the growing role of Cloud infrastructure in multimedia applications needs to be considered. For example, what additional latencies and jitter does Cloud introduce?

- Time/Frequency Support in Applications.

  This is a multi-faceted topic for multimedia and encompasses the following:
  - Determinism in runtime of software and hardware. Software includes the applications software, driver software and the underlying operating system. The concept of Time Correctness by Design would revolutionize timing performance for Multimedia applications and resulting quality.
  - Time-stamping at source. Having precision time on an endpoint, via NTP, PTP, or GNSS (e.g. GPS) is one challenge. Using it effectively is quite a different one – timestamping at source means being able to access timestamps when needed with minimal delay. Again – this is a key issue for multimedia and can greatly degrade QoS if poorly implemented.
  - Time Support within Media Protocols. For applications such as Hbb, IDMS, the need exists to map media timestamps to real UTC (or other common reference) timestamps, This facilitates transporting this relationship to end devices so that streams can be synchronised for playout, either on one device (Hbb) or on multiple devices (IDMS). RTP in conjunction with its control protocol RTCP provides one approach – eg. the RTP profile for MPEG2 relates RTP timestamps to PCR and RTCP SR packets relate RTP to NTP. Similarly, HAS applications such as MPEG-DASH have timestamps embedded in media which can be used for interesting synchronising applications.
  - Development Environments DE. As outlined above, this is a big challenge. Essentially it imagines a DE that allows developer to specify time/frequency constraints for a
multimedia application, and the environment assists in design and construction of code to meet requirements. As such the resulting application will satisfy both logical correctness and temporal correctness constraints.

Summary

This paper has presented a big-picture view of multimedia synchronisation, and outlined a range of perspectives and some resulting challenges that can, if met, help ensure that new and exciting multimedia applications continue to emerge. It draws heavily on the work of the TAACCS group that are examining similar challenges but applied in the much broader IoE. Whilst time and frequency are always a serious consideration for anyone working in media synchronisation, it is important to consider how multifaceted the challenge is to and the relationship between the various facets. Essentially, a more integrated and holistic analysis will help deliver better applications.

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