INTELLIGENT CONTENT PRE-POSITIONING USING LTE-BROADCAST FOR A MEDIA OPTIMIZED NETWORK

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ABSTRACT

With increasing mobility, end-users are accessing video content any-time, anywhere, often over congested mobile networks, leading to poor received performance. To provide the best viewing experience with superior quality, this paper presents a solution that intelligently pushes popular content to mobile devices, i.e. pre-position using LTE-Broadcast, extending beyond the current unicast pull-based approach. This solution has been developed and trialed in the Telstra network in Australia with successful outcomes. Results from live customer trial shows that this solution can potentially double the capacity through real-time network awareness for pre-positioned content delivery, while offering virtually “no buffering” high quality audio and videos to increase end-user engagement. Beyond video content, this solution can be applied for other usecases such as delivery of firmware updates to mobile devices and connected cars, accelerated website delivery, VR/360° content delivery, and targeted advertising.

INTRODUCTION

Advances in technologies are enabling the Internet to complement or even replace traditional video broadcast services, as new delivery mechanisms targeting customer experience are coming into existence. Moreover, over the last decade, our world has gone digital and transitioned to the small screen. The number of mobile broadband subscribers worldwide has reached 4.3 billion ‘Ericsson (1)’. Video is largely responsible for the growth in consumer broadband and mobile data consumption, with video expected to grow to 82% of all IP network traffic by 2020 ‘Cisco (2)’.

As IP video consumption grows, end-users are increasing their quality and reliability expectations towards the high levels they receive from broadcast. In addition, demand for trouble free viewing on their mobile—anytime, anywhere is becoming the norm. The result is a strain on mobile networks leading to a poor Quality of Experience (QoE) and declining user engagement. In the coming years, even higher user expectations and greater demand is envisaged due to new content formats (e.g. 4K/UHD, VR, 360°) and further technology accessibility. Therefore, TV scale media delivery solutions are not simply hoped for but required. Figure 1 presents a summary of how video and media services are re-shaping the global industry, along with examples in the Australian and operator context.

These trends have created a significant demand for network bandwidth availability and fostered an environment where operators and content providers rely on caching infrastructure, i.e. Content Delivery Network (CDN), globally in order to service their

customers. In addition, video delivery technologies, such as Broadcast over LTE mobile networks (LTE-Broadcast) 'GSA (4)', have evolved to leverage them. To cater for the unprecedented growth of mobile video, ensuring user QoE, operators are investing in innovative solutions leveraging various optimization, caching, and delivery technologies.

In the Telstra context in Australia, our challenge was to develop a solution that could satisfy the customer demand for a high impact QoE; create new monetization opportunities for content creators; and have cost-effective delivery outcomes. And all of these should happen without adversely impacting the current mobile network or existing customers.

Figure 1 – Global industry trends on video services and consumptions (Source: Telstra)

To this end, in this paper we present a solution called content pre-positioning. It is tailored to ensure end-user QoE, by proactively pre-loading recommended premium content to mobile devices using LTE-Broadcast and unicast as fall-back. This innovation has been trialed across the Telstra network in Australia, leveraging a transaction-based movies service, featuring full-length premium content with high quality video and audio. Results not only demonstrate end-user received experience improvement, but also offer increased engagement and network benefits through potential cost reduction and efficiency.

There is a handful of related work 'Akamai (4), Incoming Media (5)' that use unicast-based content delivery and push notifications; however, we differ in that our solution leverages LTE-Broadcast, real-time mobile network awareness and machine-learning based recommendations tailored to user interests. Specifically, the contributions of this work are:

- More reliable delivery using LTE-Broadcast than customer prompted.
- Unconstrained rich media quality through network offline usage at lower cost, leveraging CDN/LTE-Broadcast integration.
- Personalized end-user experience, ensuring targeted content, and guaranteed quality viewing.

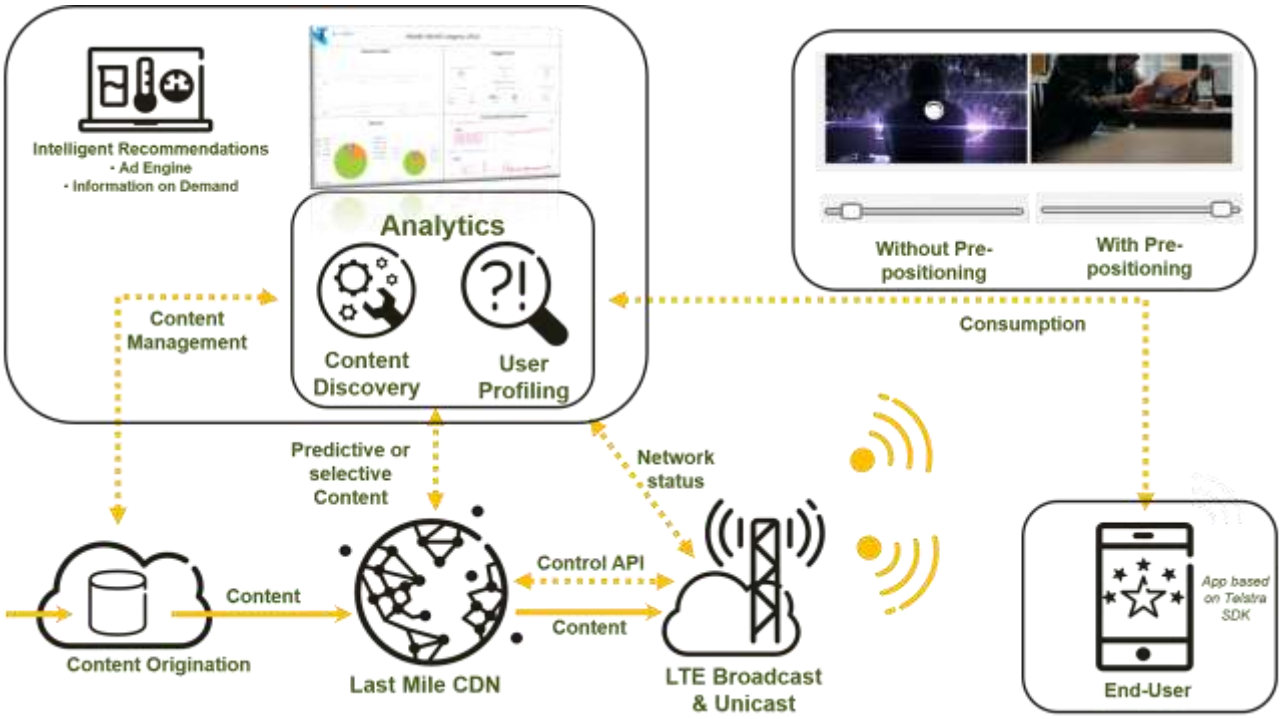

Figure 2 – End-to-end solution overview for content pre-positioning

OVERVIEW OF SOLUTION ARCHITECTURE

Content pre-positioning pushes to mobile devices, i.e. pre-position, recommended content using LTE-Broadcast. An API-driven platform is exposed to content providers to define delivery requirements, while the operator conducts network-aware content distribution, considering user preference and mobility. Application, with an integrated pre-positioning Software Development Kit (SDK), on the mobile device stores, manages and makes the content available, tailored to the user's interest. Unicast delivery is used as a fall-back to LTE-Broadcast. Figure 2 presents the solution overview.

Solution Building Blocks

The functional building blocks of the solution can be categorized as:

- **Delivery:** Content origin, CDN and LTE-Broadcast form the delivery system. Origin provides an environment to ingest media content and support the workflow required to publish the content in a form usable for the intended application on user devices. CDN receives requests for content, and if required, ingest them from the origin. Where possible, it caches content for a period to provide scale and minimize the number of requests to the origin. LTE-Broadcast ingests content from the CDN and prepare them for delivery over broadcast. It uses LTE-Broadcast delivery channel over mobile network to deliver content to users. Integration APIs between CDN and the LTE-Broadcast system allows automated scheduling for the delivery of content.
- **Control:** The control plane is composed of the content manager, and server and client-side pre-positioning control SDKs. The control SDKs allow content to be loaded onto devices that need to support pre-positioning of content. While providing

cache control mechanism, server side SDK also maintains a database of content for pre-positioning and a record of related applications on user devices. The device SDK provides a micro-caching and proxy service for caching, presentation and lifecycle management of the content on the device. The content manager binds all the components in the control plane through a workflow system to sequence the task of processing and publishing content to the application.

- **Application:** Customer application resides on the device and has pre-positioning SDK capability built into it. It also has embedded LTE-Broadcast middleware to interact with the baseband broadcast stream and present it to the application.
- **Analytics:** The role of analytics is crucial for both consumption and delivery of the pre-positioned content. While making a pre-positioning decision, the control plane takes into account the content availability, real-time network conditions, and user profiles to determine which content need to be pre-positioned. Consumption and delivery analytics are derived from the application, as well as from the network.

LTE-Broadcast and Its Role

LTE-Broadcast (also known as eMBMS, and LTE Multicast) 'GSA (4)' is an enabling technology aimed at more efficiently and reliably delivering a broad range of services and applications across mobile networks. Through the use of LTE-B, a service provider can:

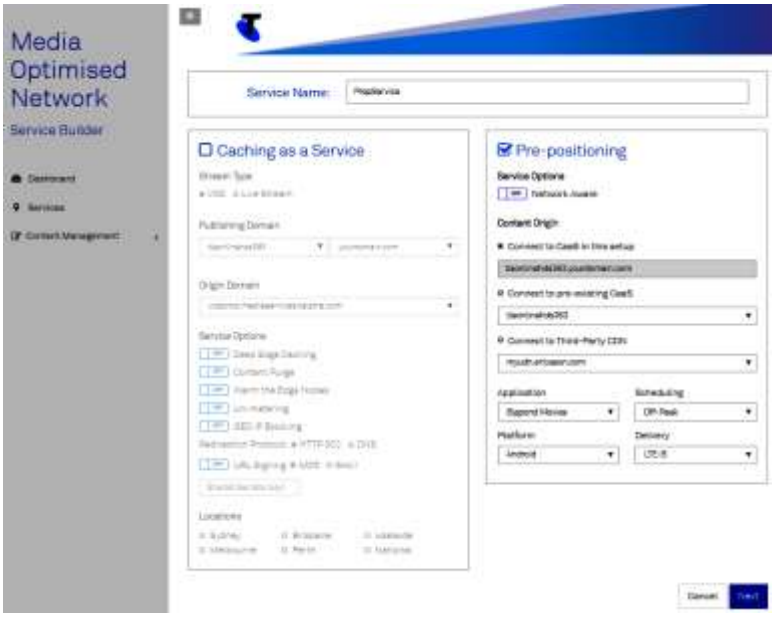

Figure 3 – Content provider interface

- Deliver a higher quality (constant bit rate, buffer-free), real-time, and/or more efficient (lower cost per bit) video experience to more users on the network.
- Support use cases for the mass distribution of media and data, including mass software updates, alerts, digital signage, mobile TV, and stadium video.

We leveraged the LTE-Broadcast capability, while integrating CDN and LTE-Broadcast for scheduling, delivery and creation of an API-driven interface. Unicast delivery mechanism is used as a fall-back for broadcast, when end-user is not in the broadcast coverage area or broadcast fails without requiring standard file recovery.

A Representative Workflow

Figure 3 shows the interface used to capture delivery requirements for the pre-positioning service. High level workflow steps are:

1. Content provider inputs origin and delivery instructions. Based on the input, content is tagged for broadcasting and delivery is scheduled using the content manager.
2. The content manager advises the server-side SDK of broadcast content, and its timing. The information is forwarded to the CDN service exposure and then to LTE-Broadcast through CDN/LTE-Broadcast integration APIs.
3. The LTE-Broadcast system confirms that a broadcast session has been created earlier, and provide all the information required for a device to tune to the broadcast, e.g. frequency, time, modulation parameters, and date.
4. Prior to the broadcast, LTE-Broadcast requests the content from CDN, using the associated URL. CDN provides the content or obtains it from the origin.
5. User device tunes to the broadcast frequency, and configures to demodulate the signal. After processing, LTE-Broadcast completes the scheduled delivery. When LTE-Broadcast is not available, content delivery is retried using unicast fall-back mechanism based on the schedule.
6. The user device receives the content, and places it into the on-device cache, under control of the device SDK. Lifecycle management in the device SDK ensures content currency, power and storage management (see results section).
7. After the device receives the content, the user is notified that new content is available for consumption. If the user chooses to play the content, application retrieves it from the on-device cache, and renders it for consumption by the user.

Content Distribution Mechanism

Content for pre-loading onto devices are sent over broadcast as a one-shot delivery. The broadcast schedule is about the same duration as the expected transfer time and typically less than the duration of video payloads. In situations when broadcast is unavailable or end-user is outside the LTE-Broadcast coverage zone, unicast is used for delivery. The Media Presentation Description (MPD)—segment information such as timing, URL, bitrate, resolution—of broadcast and unicast is synchronized so that there is a direct mapping of segment numbers of each delivery methods. For large files, broadcast requires unicast recovery mechanism to cater for lost segments.

Broadcasting of pre-positioned content is suitable for scheduled events or long-running recurring delivery cycles. Thus, it co-exists with automatic night-time download via WiFi. Our solution leverages network idle times and is therefore an alternative to other forms of distributions. In addition to pushing recommended content to user devices, the pre-positioning solution is also used to background download content when a user manually requests a specific content from the mobile application. In such cases the content delivery is done over unicast and is spaced out over a longer period of time, rather than instant download, to protect adverse impacts on the network or the device power consumption.

Role of Network Awareness

Rationale for using real-time network awareness for pre-positioning decision making are to make optimal use of resources, while efficiently managing overall customer impact. Our

solution schedules pre-positioning when the network is underutilized and shapes delivery so added traffic does not impact existing subscribers (see live trial results section).

Role of Content Recommendation

Recommendations allow us to understand the relationship between end-user and content, and ensure the right content gets to the right people at the right time. Our solution leverages machine learning-based recommendations to obtain an asset-to-user mapping to get the list of content for pre-positioning onto end-user devices. Current capabilities include declarative recommendations by content providers, as well as rules-based recommendation from a content catalog as per user profiles.

VALUE CREATION FOR THE BROADER ECOSYSTEM

For the broader ecosystem, content pre-positioning provides the foundation for a Media Optimized Network, allowing optimal, intelligent and customizable delivery of services in a means not replicable in isolation. For operators it ensures optimized delivery in a cost-effective manner by harnessing the benefits of LTE-Broadcast, off-peak delivery, and real-time network awareness. Rationale for content provider is that it offers innovative ways for users to watch relevant content seamlessly at a lower cost due to network off-peak usage.

Specific aspects of the solution such as the interface to the transport and application layers—including protocols and APIs, network and system architecture aspects—help in establishing the foundation for rich media delivery using future technologies, such as 5G.

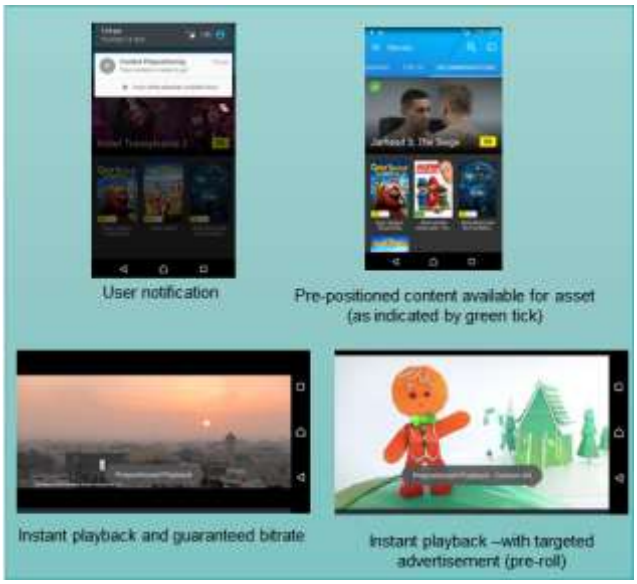

Figure 4 – Application features

Business Model

When video consumption is increased through data, differentiation and content, a number of monetization opportunities can be created. Unique and consistent customer experience for various product offerings are enabled by pre-positioning. It allows introducing business models with transaction and/or subscription based pricing for zero-rated off-peak delivery.

Cost Reduction Potential

This innovation has potential to decrease the unit cost of delivery in a mobile network. Due to the use of LTE-Broadcast, granular network condition prediction, off-peak delivery, and consideration of user impact from content delivery ensure that the network is optimized for unconstrained media delivery. LTE-Broadcast offers to deliver content at approximately 5 times the cheaper rate, whilst the upfront implementation cost is justified through less than 1% of busy hour unicast traffic conversation to multicast ‘LTE-B Alliance (6)’.

CUSTOMER TRIAL OUTCOMES

The solution has been trialed for a transaction-based movies service with Digital Rights Management (DRM) protected entertainment content (example app overview in Figure 4). The objective was to test the technical capability, content quality and end-user engagement. Trial scope was:

- Personalized pre-positioning with content promotion and discovery.
- Ability to offer seamless experience and instant play for licensed content.
- Content consumption and network analytics, along with user surveys.

Quantitative and Qualitative Results

Table 1 shows a snapshot of comparative playback results, during a representative time-range: 28 March–12 April 2017, between pre-positioned and streaming content from the live customer trial. Complete trial results demonstrate that pre-positioned content has higher quality (3x greater average bitrate and 5x lower buffering ratio), instant start experience (3x faster average start-up time), and higher user engagement compared to the same streamed content (77% vs 17%). With long-form content consumption making up majority of time watched on every screen—connected TVs (98%), computers (65%), tablets (81%), and smartphones (55%) 'Ooyala (7)'—there is high relevance and potential necessity for pre-positioning of full-length premium content and TV shows on mobiles.

Metrics	Play On Device	Play Streamed
Plays	763	267
Total Mins	7.7k	601
Plays/device	15.8	5.51
Mins/device	157	12.3
Avg. bitrate (Mbps)	6.33	1.8
Re-buffering %	0.86	9.91

Table 1 – Playback overview analytics

Figure 5 – Network-aware pre-positioning (Source: Uhana)

From the survey results, instant play and buffer-free viewing are identified as the most important factors for driving engagement and viewing. As it is evident, pre-positioning solution offers virtually "no-buffering" for the playback. During the full trial period (March–May 2017), the re-buffering percentage was 0.32% (0.86% vs 9.91% in the representative time-range). The non-zero re-buffering resulted from several contributing factors, including the time required for clearing licenses for online to offline viewing, as per user mobility. Moreover, application versions mismatch; user movements into congested cells during license transactions; even traveling and accessing from overseas, contributed to re-buffering.

In the accompanying tests, we leveraged real-time prediction measures, based on mobile cell traces (ingested from 258 cells, 86 eNodeBs). The outcome is 2% False Accepts and 16% False Rejects for predictive network-aware pre-positioning decisions. Melbourne CBD results show that network-aware delivery offers 30-40% of efficiency gain without any impact. Although doubling the mobile network capacity could be achieved for pre-positioned content with less than 10% of customer impact (Figure 5).

Impact on End-User Devices

Our solution is designed for minimal impact on end-user device performance. To cater for large files of up to 6GB, in the trial we have utilized a combination of internal device storage (32GB) and external microSD cards (200GB). Maximum 2 recommended content per week were pre-positioned, while users could manually request more content for background download. End-users have been given control in the application to specify storage destination, storage space, and number of content that can be stored. Content storage is private to the application and is formatted by the mobile operating system when the application is uninstalled. Storage management in the device uses Least Recently Used (LRU) algorithm, while there is option to remotely purge content across devices.

The pre-positioning device SDK stays in “dormant” mode all the time, unless otherwise instructed. When the device tunes into broadcast, it is awake to process the broadcast stream, even though the end-user is not physically interacting with it. While broadcast does not provide any significant improvement in power consumption over unicast, the overhead to keep the device awake and radio/WiFi always ON is much larger. Trial results show that when content pre-positioning is active, with moderate use of other applications, a typical battery consumption rate is less than 10% per hour. Therefore, recurring large and continuous delivery of files are to be done when the device is charging. In a commercial offering, it is envisaged that custom cache policy, power consumption, and storage management approaches will be employed to align with the product proposition.

Key Takeouts

Our key learnings from the content provider engagement and the live customer trial are:

1. Customers want high quality videos and fewer interruptions for “worry-free” viewing.
2. Better QoE = more user engagement. Instant start is key for consumption behavior.
3. Content providers want premium experience on every device for their customers.
4. Operators need to create differentiated service to enter in the content value chain.
5. Pre-positioning unlocks several media usecases that resonate with customers.

OTHER PRACTICAL APPLICATIONS AND FUTURE DIRECTIONS

Pre-positioning complements live streaming. While watching a live game, the audience in the stadium can have highlights, stats, and player profiles loaded onto the device for instant viewing and later consumption. Operators can make the ride enjoyable for daily commuters, by pre-loading personalized News, TV shows or full/partial movies onto mobile devices. Moreover, several product offerings for usecases such as application/firmware delivery to mobiles and connected cars, and VR/360° content delivery can be enabled.

There are several future extensions to mobile pre-positioning. By leveraging a residential hybrid gateway (with fixed and mobile connectivity) 'Telstra Exchange (8)', pre-positioning can be used to store software updates and content catalog in the connected storage at home. Pre-positioning can enable predictive streaming—the ability to deterministically stream videos at higher bitrates using LTE-Broadcast or unicast, taking advantage of network "micro-troughs" 'GSMA (9)'. Pre-positioning of non-video content, especially website embedded objects can be delivered and stored onto the device just-in-time to allow fast website loading and a superior browsing experience. As for advanced content discovery, future work can harness trends in the network and social media, combined with contextual metadata to make hyper-targeted recommendations for pre-positioning content.

CONCLUSION

The global industry is rapidly changing due to opportunities offered by new technologies for delivering media services. Content pre-positioning is a powerful technology innovation that can help make mobile video mainstream by shifting consumer usage from low to medium range to the higher end, in turn attracting new customers. Pre-loading the content onto devices seek to eliminate impacts of fluctuating network and improves QoE. It allows better utilization of network resources and create monetization opportunities. Overall, operators can not only create service differentiation, but also can offer cost-effect delivery proposition to content providers and guaranteed higher quality to end-users.

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ACKNOWLEDGEMENTS

Telstra thank 21st Century Fox and Fox Innovation Lab for providing content for the Content Pre-positioning trial, and Ericsson for providing enabling platforms for content

preparation and delivery. Real-time network awareness and prediction measures were obtained through the Uhana platform. Finally, we express our gratitude to the wider Telstra team for their support and contribution. All pictures have been sourced from Telstra work.