Home-Boxes: Context-aware distributed middleware assisting content delivery solutions

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ABSTRACT
Within the Future Media Internet, residential gateways, involving overlay network creation, are foreseen to become an efficient alternative solution for content distribution. This poster proposes a new residential gateway middleware approach, called the Home-Box (HB), exploiting an innovative popularity-based and collaborative caching strategy, able to achieve scalable and cost-effective Video-on-Demand (VoD) services. The middleware offers to Content Providers an efficient way to get media content closer to End-Users. Besides, the caching mechanism is coupled with context-aware features in order to select the best serving HBs, leveraging the HB middleware overlay with an overall load-balancing system. The solution has been implemented and deployed in a large scale test bed; results outline the Home-Box, in collaboration with its neighbors, as a suitable and rightful asset alternative and/or complementarity to existing VoD service infrastructures such as Content Delivery Networks.

General Terms
Algorithms, Management, Measurement, Design.

Keywords
Media-oriented middleware, overlay network, context-awareness, home-gateways, media delivery, replication, Future Media Internet

1. INTRODUCTION
Users’ demands on VoD services consumption have seen a tremendous increase and will exponentially grow in a near future [1]. As the broadband connectivity becomes pervasive, the End-Users expectations for a better quality of experience in disparate environments increase. The need for new, ubiquitous, scalable and reliable video services has never been higher.

The scalability and reliability issues are commonly addressed by the use of content replications. Indeed, a higher distribution means shorter distances between content servers and consumers, thus minimizing latencies and reducing network bandwidth consumption, as well as probabilities that packet loss occurs. Content replication is performed in geographically distributed nodes, in order to bring the data closer to the End-Users. Content Delivery Networks (CDNs) and P2P are competing technologies that make use of replication. Although CDNs offer high service availability, they come at important scaling costs when considering the continuous growth of VoD popularity. On the other hand, the P2P technology proposes a low cost solution. By trusting users behavior, the P2P approach could scales very well. However, lack of control and management, high peer churn and imbalance between uplink and downlink capacity have prevented P2P to be widely deployed for video distribution.

The proposal presented in this poster introduces the new Home-Box (HB) middleware. The HB represents a centralized element in the content delivery chain, making the bridge between the End-User environment, the service environment, and the network environment. Aiming at enhancing today’s home-gateways, the HB (owned by Service Providers (SP)) incorporates delivery services in addition to the existing network functionalities. The Home-Box middleware’s purpose is to establish a hybrid CDN-P2P virtual layer, running on top of existing service environments. Moreover, an effective collaboration among Home-Boxes enables already cached content to be shared within the Home-Box virtual layer. Hence, the HB middleware is seen as an extension of the CDN. This HB, as an always-connected middleware, consists of an online and dynamic collaborative caching strategy coupled with a context-aware peer selection mechanism that determines the best serving Home-Box. Recent works have proposed architectures that rely on boxes deployed at the edges of the network, close to users’ terminals, for live video streaming services [2] or VoD services [3]. However, in the latter, video contents are placed offline only, which involves an additional delivery cost.

Since HBs are middleware running on top of already existing and deployed home-gateways, the scaling costs faced by CDNs are not a concern; the virtual overlay would almost linearly expand with the number of users. By leveraging the HB disk caches and upload capabilities, the HB overlay could reach the required scalability and reliability for content delivery services by providing an asset to already existing content distribution platforms. Furthermore, service performance could be dramatically enhanced, especially in the current context where Network Providers are heavily investing in their high-speed last mile networks.

The concept has been adopted within the European project, ALICANTE, as part of the proposed architecture for Future Media Internet.

2. HOME-BOX MIDDLEWARE MODEL: ENABLING CONTEXT-AWARENESS AND EFFICIENT CONTENT DISTRIBUTION

2.1 Collaborative Caching Mechanism
In the case of High-Popularity VoD distribution, enabling distributed caching capabilities at the edge nodes is seen as a very welcome add-on to the traditional cluster of VoD servers. An efficient HB caching and replication solution is therefore required in order to obtain scalable content distribution. This solution is composed of (1) an online collaborative caching strategy and (2) a cache management system performed by SP.

Within the proposed collaborative caching approach, as depicted in Figure 1, the SP may use the local HB resources, namely its storage capabilities, to push content in advance before it is being requested for consumption. The SP keeps full control of what and where this content may be pushed into. In addition, HBs perform an effective online collaborative caching. Contents are cached on HB while End-Users consume the media contents; in the mean time, efficient communications between HBs allow cache discovery in remote HBs in order to retrieve the sought contents from those HBs. Hence origin servers could see important offloads since media delivery is achieved from the HB middleware overlay.

The HBs are organized in Virtual Home-Box Overlay Networks, which can be managed by a Virtual Home-Box Provider or by a Network Provider that own the Home-Boxes. In the last case, the Network Provider may build a CDN-like infrastructure by using
the Home-Boxes at the End-Users’ premises. Figure 2 exposes our proposal. The data streams are represented by red arrows while management communications are represented by green arrows.

![Figure 1: Collaborative Caching Approach](image1.jpg)

**2.2 Home-Box Distance selection mechanism**

This poster proposes an innovative approach consisting of an adaptive algorithm selecting the ‘best’ neighboring Home-Boxes that could handle requests. This selection considers HB context, as well as the underlying network conditions. Two groups of HB Distance metrics classify these types of information: HB resource metrics and Network Distance metrics.

The HB Resource metrics refer to the current utilization of CPU and network resources of a given HB. In this sense, candidate peers, which have a “small” Network Distance but are currently overloaded, might not be selected if other HBs with higher Network Distance exist but are in idle state. The HB Resource metrics of HB h are made available on each HB and are: \(c_h^{(1)}\) the CPU utilization of the HB h in percentage; \(c_h^{(2)}\) the inverse of the network interface (bandwidth) in seconds/Gbits; \(c_h^{(3)}\) the access interface utilization, as percentage of its maximum capacity.

The Network Distance metrics define the network “cost” for the interconnection between a HB \(a\) and a HB \(h\). When a service is available from multiple HBs, the “nearest” HB is selected. Network Distance metrics are: \(c_{ah}^{(4)}\) the number of hops traversed; \(c_{ah}^{(5)}\) the average one-way delay (in \(\mu\)sec); \(c_{ah}^{(6)}\) the average packet loss; \(c_{ah}^{(7)}\) the average jitter (in \(\mu\)sec); \(c_{ah}^{(8)}\) the percentage of duplicated packets.

The HB Distance between HB \(a\) and HB \(h\) is defined by a vector:

\[
C_h = (c_h^{(1)}, c_h^{(2)}, c_h^{(3)}, a_h^{(4)}, a_h^{(5)}, a_h^{(6)}, a_h^{(7)}, a_h^{(8)}) = (c_h^{(i)}, i = 1, 8)
\]

The HB Distance provides some significant criteria to rank a pool of available remote HBs. The overall aim of defining our novel neighbor-ranking algorithm is to optimize the overall performance of the content delivery system. The proposed ranking decision algorithm follows the multi-criteria optimization approach, where several metrics are taken into account (the above-mentioned HB Distance metrics) in order to efficiently find an optimized solution for the set of HB distance vectors. The algorithm is based on the approach of the reference level decision, and takes into account the impact of network distance and HB resources, and dynamically adapts the decision to the current state of the system. The latter ranking algorithm is performed at HBs. More information about the proposed algorithm can be found in [4].

**2.3 Middleware architecture layering**

The overall middleware-layered architecture is depicted in Figure 3. It consists of two layers: the bottom layer represents Input/Output interfaces; the upper-layer is the middleware’s core that includes the inner-modules responsible for the above-mentioned mechanisms (e.g., collaborative caching, HB Distance selection mechanism, overlay creation).

![Figure 3: HB Middleware](image2.jpg)

**3. RESULTS & CONCLUSIONS**

A recent study [5] focused on the choice of neighbor numbers. As this number grows, the caching efficiency improves. This collaborative caching efficiency induces communication costs that cannot be neglected. An optimal trade-off was found between caching efficiency and network friendliness. Results have shown that the optimal state can be reached for 25 neighboring HBs, with more than 60% of incoming request being handled by the Home-Box overlay. Hence offloading clusters with more than 60% of incoming requests.

In addition, experiments conducted within this poster scope demonstrated a dramatic increase of the HB overlay efficiency when the HB Distance selection mechanism was in use; in comparison with the classical HB selection scheme, (which is to select the first neighboring HB positively responding to content lookups). 30 HBs were dispatched on three pilot islands with a 75-video library made available (each video being 2.2 MB). As a result, the use of our HB selection mechanism showed out 50% more requests being handled and processed by the HB overlay.

The HB Distance selection mechanism provides a strong advantage to the overall system by fairly distributing the load across HB according to their service availability. We can conclude the HB-assisted solution with the online collaborative caching strategy and the novel context-aware selection algorithm can efficiently enhance content delivery of already existing distribution platforms.

**4. REFERENCES**


