# Peer-to-Peer Mobile Video On-Demand for Multiple Diverse Mobile Wireless Systems

Katsuhiko Sato† Michiaki Katsumoto††† Tetsuya Miki††

†Japan Radio Co., Ltd. ††The University of Electro-Communications
†††National Institute of Information and Communications Technology

**Abstract**

**We propose a new form of distributed multimedia communication and service architecture, peer-to-peer mobile video on-demand (P2MVOD) for multiple diverse mobile wireless systems. Our previously proposed P2MVOD [20] allows a moving client to receive streaming data on demand from not only server but other moving clients in a peer-to-peer (P2P) manner. In this scheme video contents are divided into the same sized segment and broadcast into the network to overcome mobile routing overhead. Broadcasting obviously consumes much network bandwidth, but the segment aggregation strategy allows content to be shared with as many receiving clients as possible, thus counteracting the resulting increase in traffic. In this paper, we design P2MVOD service architecture for multiple mobile wireless access network systems such as WiFi and WiMAX. This architecture allows P2MVOD to efficiently provide its service at the same time for multiple network domains with different request rates.**

## I. INTRODUCTION

Broadband wireless access and mobile network technologies enable the distribution of rich content and the provision of a wide range of services such as TV like video broadcasting and on-demand video delivery services to mobile users. In our previous publication [20], we proposed peer-to-peer mobile video on-demand (P2MVOD)—a new real-time video distribution scheme, which is a form of next-generation distributed multimedia communication. In this scheme, video content can be distributed, using a peer-to-peer (P2P) scheme, on demand from not only server but clients that are moving anywhere. The main advantage of using a P2P is that a large number of clients share the burden of server for providing content (processor time and network bandwidth). P2MVOD decentralizes video content by distributing it amongst clients. Clients cache parts of the content and provide them to each other. In addition, P2MVOD allows clients to move around freely even while sending and receiving video streams.

In general, VOD service is realized through unicasting in which video data is carried to each user in separate flows. This approach consumes a great deal of network bandwidth resource and is unacceptable for wireless basis mobile network system. To overcome this problem, we apply multicast VOD technologies, which are promising for on-demand video distribution to reduce the required network bandwidth using multicast techniques. In these technologies, video content is transferred by multicasting and shared by clients who submit requests at around the same time. Clients who submit later requests individually receive the initial parts of the multicast data via unicasting.

However, multicast VOD technologies cannot alleviate a burden on the server system. We then focus on a new multicast VOD technique that uses P2P scheme, where the initial parts of video content is provided by clients that already received and cached it. Even though we use this strategy, however, extremely complicated mobility control on multicast and unicast routing is required when we give the mobility to clients sending and receiving video streams.

Our proposed P2MVOD solves this issue by dividing video content into the same sized segments and broadcasting them. Broadcasting eliminates the mobile routing overhead of unicast and multicast routing protocols. Segmenting the content enables multiple clients to share the accountability for providing the initial part of content. A client can easily receive content from any clients by broadcasting. Although broadcasting clearly is a bandwidth-consuming method, each segment is aggregated so that it can be shared with as many receiving clients as possible. The aggregation effect is expected to counteract the increase in network traffic due to broadcasting.

To obtain maximum effectiveness of the aggregation, the segment length must be determined based on the rate of requests. In this paper, to allow P2MVOD simultaneously perform in multiple delivery infrastructures that have respectively different request rates, the segment is further divided into smaller sized unit referred to as slice and its length is expressed as the number of the slices. As a result, P2MVOD can provide its service simultaneously to multiple mobile wireless network systems. The rest of this paper gives more detailed P2MVOD description (Section II and III) and the new strategy of slicing the segment (Section IV), and a design of P2MVOD service architecture for multiple mobile wireless network systems, WiFi and WiMAX (Section V), and detailed control procedures on it (Section VI).

## II. MULTICAST VOD

A number of effective VOD techniques using multicasting have been reported. Batching [1], piggybacking [2], and the block-transfer-based techniques of Woo and Kim [3] and Kalva and Fuhrt [4] are early examples of multicast VOD technologies. Carter and Long [7], Hua and Cai [8, 9], and Gao and Towsley [10] reported patching techniques based on streaming-transfer techniques, which are fundamental to current multicast VOD studies. P2Cast [17] applied patching to a P2P-based VOD scheme.

Patching technique greatly reduces the bandwidth required on the network compared with the simple VOD scheme using unicast only, while allowing clients to immediately play back content. In this technique, video content sent via multicasting is called a shared flow because it is shared by clients who make requests at around the same time. The initial part of the content data, which is not available to clients that make later requests, is individually delivered to these clients through unicasting; this is called a patch flow. The shared data are not played back immediately, but are buffered until the patch flow data have been completely played back (Fig. 1).

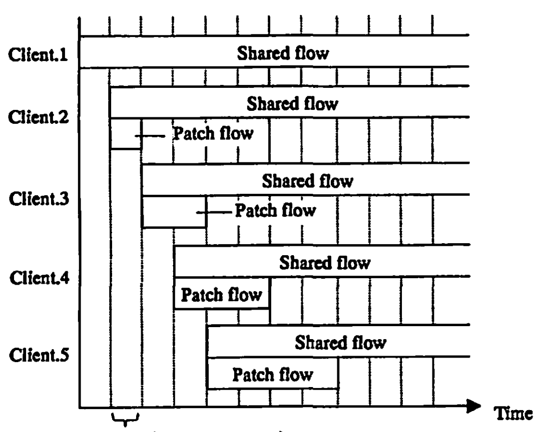


Figure 1. Patching technique.

## III. P2MVOD

Our P2MVOD [20] is also based on patching and takes the mobile environment into consideration further than P2Cast. P2MVOD divides video content into same-sized segments. Both shared and patch flows are transmitted in series of segments. This allows clients to share the reception of patch flows as well so that the traffic is further reduced. Clients that have already received and cached segments provide them through shared and patch flows.

How the segments are delivered and shared is shown in Fig. 2. Clients 1–5 request video content in order. Assume that the request rate is $\lambda$ and the request interval is $1/\lambda$. Client 1, who makes the first request, receives the shared flow only. Clients 2–5, who make subsequent requests, receive both the shared and patch flows. The video content is divided into the same sized segments, $s1, s2, \ldots$, with lengths of $1/\lambda$.

Take Client 4, for example. It submits its request $3/\lambda$ after Client 1's request, so Client 4 then needs a patch flow that includes three segments: $s1$, $s2$, and $s3$. In this case, $s1$ and $s3$ must be newly provided, but $s2$ can be shared with Client 3. In the figure, the segments that can be shared with a previous client are shown in gray. We can see that $s1$ must be provided for every client request, $s2$ must be provided for every second client request, and $sn$ must be provided for every $n_{\text{th}}$ client request.

The most important design feature is the segments are provided by clients instead of a server. For example, Client 1 can send $s1$ to every subsequent client; Client $n$ can send $sn$ to every subsequent client. Because the segments are broadcast, a client can easily receive them from multiple clients.

It is considered that the total number of segments in the patch flow remains approximately the same whether the request arrival is random or uniform, in other word, the required bandwidth is not affected so much by requests arriving at random. A request prior to the normal time allows the client to receive more segments that are to be dispatched to the previous clients. Meanwhile, the delayed request to the normal time allows more subsequent clients to share the segments to be dispatched to the client.

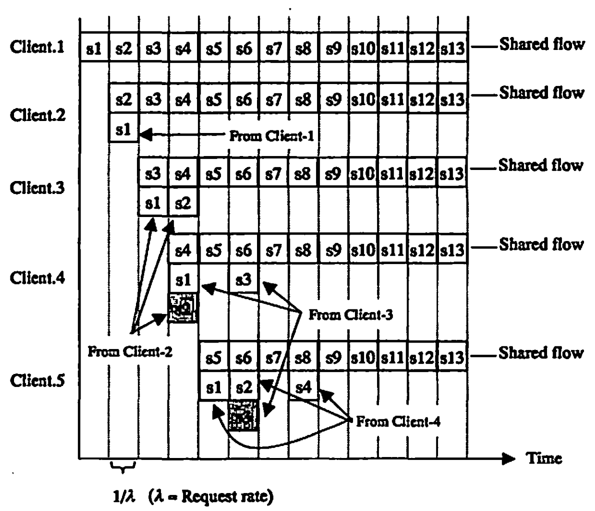


Figure 2. P2MVOD: segments shown in gray are shared with other clients; i.e., they are not actually sent.

## IV. SUPPORT FOR DISTRIBUTION TO MULTIPLE DELIVERY DOMAINS

To maximize the effectiveness of aggregating segments among receiving clients, the segment length is set to the reciprocal of the average arrival rate of requests. Here, each segment is decomposed and composed of the same sized unit referred to as slice (Fig. 3). The segment length is expressed as the number of the slices, for example X, Y and Z as shown in the figure. The slice length is fixed and unchangeable (irrelevant to the request rate), and is by far smaller than request interval.

This slicing strategy allows a single server to transmit different sized segments to multiple distribution domains that would have respectively different request rates. Figure 4 examples that there are different types of mobile wireless access system, WiFi, WiMAX and 3G, whose request rates are $\lambda_1$, $\lambda_2$ and $\lambda_3$, respectively. A length of the slice can be dynamically determined as the greatest common factor of lengths of the segment for all systems. In case that $1/\lambda_1$, $1/\lambda_2$ and $1/\lambda_3$ are respectively 100, 80 and 60 for example, the slice length is determined as 20.

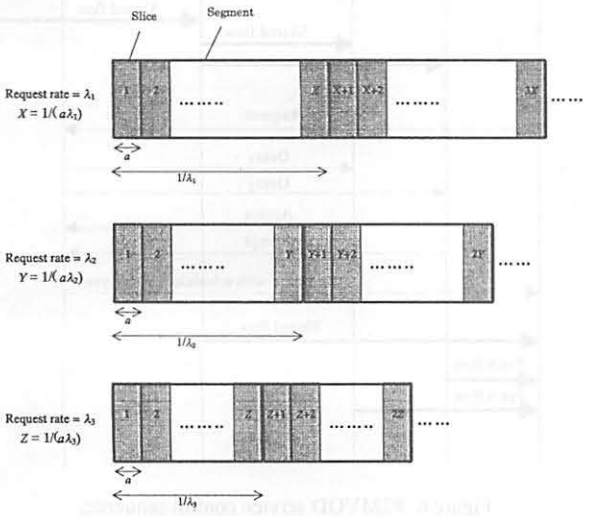

Figure 3. Segment and Slice

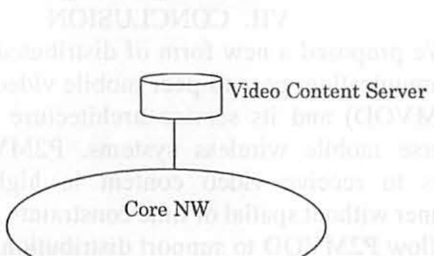

Figure 4. Distribution to multiple domains

## V. ARCHTECTURE DESIGN OF P2MVOD FOR MULTIPLE MOBILE WIRELESS SYSTEMS

Figure 5 depicts implementation design of the P2MVOD for multiple mobile wireless systems, WiFi and WiMAX. One of the most expected applications over the next mobile system is rich content delivery service such as TV like live-video broadcasting or on-demand video delivery to mobile users.

The design architecture consists of two types of wireless access network (WiFi and WiMAX, respectively), a core network and an application service network (this might be IMS (IP Multimedia System)). The wireless access network provides radio access to MS (Mobile Subscribers). It consists of APs (Access Point) / BSes (Base Station) and one AR (Access Router) / ASN-GW (Access Service Network Gateway). They provide media access and security controls over each air link and micro mobility management within each network. The core network is defined as an intermediate network that provides IP connectivity, AAA (Authentication, Authorization and Accounting for the network access) and macro mobility management. It allows MS to connect to the Internet, various application service networks and other type of wireless access networks. The application service network provides various kind of multimedia content distribution service, here, it provides the video streaming delivery.

We here define each wireless access network as P2BD (Peer-to-Peer Broadcast Domain) where P2MVOD performs with a single request rate. In addition, we define two types of server - video contents server and delivery control server -, and deploy them in the application service network (or might be IMS in future). The contents server sends a video content to ARs and ASN-GWs by either unicast or multicast. The video data (formed to a series of the slice by the content server) are transferred in the streaming manner. AR and ASN-GW broadcast the received stream to all APs and BSes of its own P2BD, and the AP and BS forwards it on the air link. The data provided by the server is the shared flow, which is repeatedly dispatched at interval of $h$ (video content length, which minimizes the traffic intensity as will be later discussed in Appendix). Meanwhile, the patch flows are provided by clients and broadcast throughout a P2BD. AR and ASN-GW thus broadcast the patch flow data received from clients to all APs and BSes of each P2BD.The AP and BS broadcast them to MSes through the air link as well as the shared flow data.

The delivery control server consists of AAA functions (for accessing contents) and schedulers for the patch flow delivery per P2BD. Each scheduler calculates the average request rate for its responsible P2BD and determines the segment length expressed as the number of the slices. It possesses information on the segments that can be provided by the clients that are storing them. Every client knows the delivery control server's address and submits a request for video delivery to it. On receiving a request, the scheduler searches for a client having segments as initial part of the content in the same P2BD and forwards the request to that client. The scheduler holds and maintains a schedule that describes the time at which individual segments must be sent. By referring to the schedule, the scheduler determines the segments that must be sent to the new client as patch flow and searches for other clients that can provide these segments. Further, it queries them regarding the possibility of sending the segments at a time determined by it. The clients receiving the patch flow do not need to know the identities of the clients providing the segments.

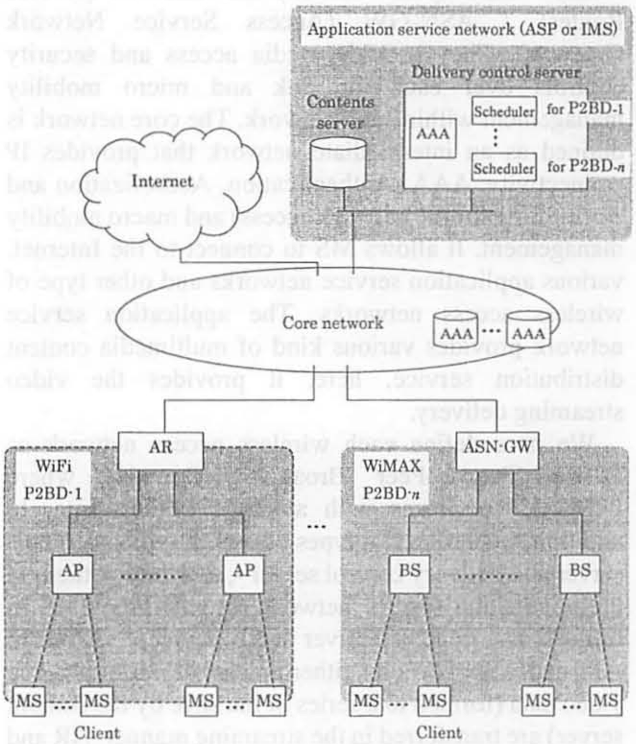


Figure 5. P2MVOD service architecture over mobile network system

## VI. CONTROL PROCEDURE

Fig. 6 shows a control sequence on the above system. Clients 1 and $i$ already receives a shared flow broadcast by AR/ASN-GW and patch flows broadcast by other clients. The scheduler records the time $T_1$ that the shared flow started. The control server also records the time that Client 1 and $i$ might be able to provide each segment of the content to later clients.

Client $n$ (the $n$th client after Client 1) sends a request for the same video to the delivery control server at time $T_n$. Receiving the request, the scheduler calculates the elapsed time ($T_n$ - $T_1$) and obtains the set of segments that Client $n$ needs (i.e., segments for $T_n$ - $T_1$ from the top, denoted as Set $\alpha$). Referring to the schedule it manages, the scheduler determines the set of segments (Set $\beta$) that needs to be delivered to Client $n$ by eliminating from Set $\alpha$ the segments that have already been scheduled to be delivered (to Clients 1,…, $n$-2) and sent at $T_n$ or later (namely, the segments that Client $n$ can receive). The scheduler then determines the time when each segment of Set $\beta$ will be sent and selects clients to provide it from Clients 1,…, $n$-1. In the figure, Clients 1 and $i$ are selected. The control server then queries Clients 1 and $i$ on whether they can provide the segments at the determined time. If Clients *1 and i can* do so, the scheduler adds the time when each segment of Set $\beta$ will be sent to the schedule and records the time when Client $n$ will be able to provide each segment of the content to later clients. The delivery control server provides the delivery schedule of Set $\alpha$'s segments to Client $n$. Client $n$ receives the shared flow broadcast from AR/ASN-GW and the patch flow segments broadcast from Clients 1,…, $n$-1 according to the schedule. Client $n$ does not need to know which clients send each segment.

The network does not need any routing control functions to distribute the segments if the WiFi and WiMAX network already forms tree topology in physical or logical.

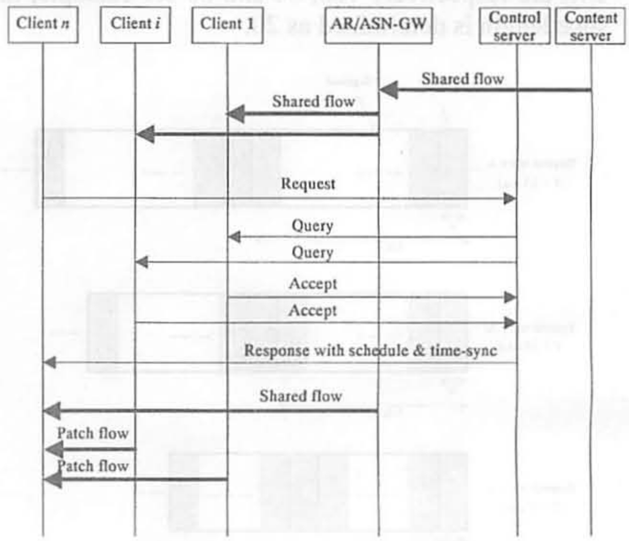


Figure 6. P2MVOD service control sequence.

## VII. CONCLUSION

We proposed a new form of distributed multimedia communication, peer-to-peer mobile video on-demand (P2MVOD) and its service architecture for multiple diverse mobile wireless systems. P2MVOD allows users to receive video content in highly efficient manner without spatial or time constraints. In this paper, to allow P2MVOD to support distribution for multiple delivery network domains that have respectively different request rates, we further divided the video segment defined in P2MVOD into smaller sized units referred to as the slice. Using this strategy, we designed a service architecture over multiple wireless mobile systems, and showed detail control procedures on that.

As future works, we will specifically design the control procedures together with particular transport, network and link layer protocols, considering how to give each layer's identifier or address to each of segments and slices.

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## APPENDIX. MATHEMATICAL ANALYSIS FOR P2MVOD TRAFFIC ON NETWORK

As discussed in our previous publication [20], to support the mobility of clients sending and receiving video streams based on multicast VOD technology, extremely complicated mobility control of multicast and unicast routing is required to individually deal with each moving source and destination. To overcome this overhead of the network control, P2MVOD takes broadcast methodology. But the broadcast strategy in general introduces the increase in traffic. This appendix shows the network bandwidth required for P2MVOD and analyzes the segment aggregation effect and the characteristics of the traffic.

The required network bandwidth can be expressed as the traffic intensity (Erlang), which is the product of the average request rate, the average flow length, and the average flow bandwidth.

Let $h$, $\lambda$, and $\tau$ denote the length of video content, the request rate, and the rate at which shared flows are generated. We assume that the content is transmitted at a constant bit rate with a bandwidth of 1. It is assumed that the requests arrive randomly within a short time span; i.e., each request occurs independently without any correlation with other requests.

We consider the traffic intensity of shared flows first (See Figure 2). The bandwidth, $b_{\text{shared}}$, the rate, $r_{\text{shared}}$, and the length, $l_{\text{shared}}$ of a shared flow are

$$b_{\text{shared}} = 1$$

$$r_{\text{shared}} = \tau$$

$$l_{\text{shared}} = h$$

The traffic intensity of shared flows is then

$$\rho_{\text{shared}} = b_{\text{shared}} \times r_{\text{shared}} \times l_{\text{shared}} = \tau h$$

Now we consider the traffic intensity of segmented patch flows. The bandwidth, $b_{\text{patch}}$, and the rate, $r_{\text{patch}}$, are

$$b_{\text{patch}} = 1$$

$$r_{\text{patch}} = \lambda - \tau$$

As shown in Fig. 2, the total length of segmented patch flows can be expressed as

$$n \times \frac{1}{\lambda} + \left\lceil \frac{n}{2} \right\rceil \times \frac{1}{\lambda} +, \ldots, + \left\lceil \frac{n}{n-1} \right\rceil \times \frac{1}{\lambda} = \frac{1}{\lambda} \sum_{k=1}^{n-1} \left\lceil \frac{n}{k} \right\rceil$$

$$n = \lambda / \tau - 1$$

where $n$ is the number of patch flows between two shared flows. The average $l_{\text{patch}}$ is

$$l_{\text{patch}} = \frac{1}{n} \times \frac{1}{\lambda} \sum_{k=1}^{n-1} \left\lceil \frac{n}{k} \right\rceil = \frac{1}{\lambda(\lambda/\tau - 1)} \sum_{k=1}^{\lambda/\tau-2} \left\lceil \frac{\lambda/\tau - 1}{k} \right\rceil$$

The traffic intensity of segmented patch flows is then

$$\rho_{\text{patch}} = b_{\text{patch}} \times r_{\text{patch}} \times l_{\text{patch}}$$
$$= \frac{\lambda - \tau}{\lambda(\lambda/\tau - 1)} \sum_{k=1}^{\lambda/\tau-2} \left\lceil \frac{\lambda/\tau - 1}{k} \right\rceil$$

Therefore, the total traffic intensity of P2MVOD is

$$\rho_{\text{f}} = \rho_{\text{shared}} + \rho_{\text{patch}}$$
$$= \tau h + \frac{\lambda - \tau}{\lambda(\lambda/\tau - 1)} \sum_{k=1}^{\lambda/\tau-2} \left\lceil \frac{\lambda/\tau - 1}{k} \right\rceil \quad (1)$$

Figure 7 shows the minimized traffic of P2MVOD. The curves in the figure is the functions $\rho_{\text{f}} = f(\lambda)$ from Eq. 1. The video length, $h$, is 2. For Eq. 1 the rate of shared flow, $\tau$ that minimizes traffic was computed for each $\lambda$.

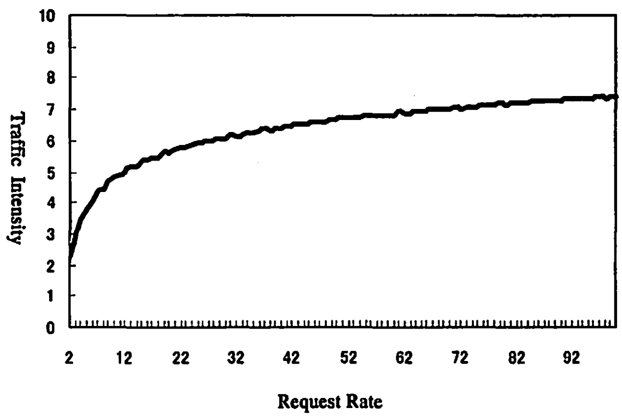


Figure 7. Minimized traffic intensity.

The computed $\tau$ was almost $1/h$ at any request rate. The traffic for shared flows with P2MVOD is almost constant for any request rate, or its traffic intensity is always 1). In other words, with P2MVOD, the traffic increase is due only to a rise in patch flow traffic. Fig. 7 indicates at a higher request rate, the gradient of the traffic intensity is small. In the Ref. [20], mathematical analysis indicated that P2MVOD reduces the traffic compared to the patching technique, although it adds to traffic when the request rate is low. This is because the increase in the rate of the traffic intensity (the gradients of the curves) is much less with P2MVOD than with patching.