Localising Peers in P2P Live Streaming Systems Within Resource-Constrained Networks

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Abstract— **The use of locality within peer-to-peer (P2P) networks is showing promise, ensuring the construction of overlay networks that are both economically viable for network operators and scalable, ensuring the successful delivery of content. However, the underlying protocols on which P2P overlays are based were originally designed as a best-effort, non-real time transfer medium which is now rapidly having to evolve in order to better support more time sensitive, real-time video delivery systems. This shift places greater demand on locality mechanisms to ensure the correct balance between bandwidth savings and successful timely playback. In this paper, we continue our work to resolve the strong trade-off resulted from the limited network condition in order to support efficient P2P live streaming services. Based on our findings we propose an OPLoc framework for supporting locality and harmonised play points in a live streaming P2P system. We present our results and analysis of its operation through a series of simulations which measure bandwidth consumption at network egress points, failure rates and each peers' play point relative to the live stream.**

I. Introduction

Enhancements in last 20 years in network capacity and mechanisms to support video distribution across the Internet have resulted in the widespread availability of live-streaming video services. Services such as YouTube [1], online TV offered by PPLive [2], the BBC iPlayer [3] and video communication by Skype [4] all highlight the new possibilities of the Internet. Multimedia video over the Internet has become a dominant application and combine with ubiquitous network access and mobile devices now makes the potential for anywhere and anytime video services. One of the established approaches for delivering video is to use a Content Distribution Network (known as a CDN).

A CDN consists of a number of dedicated CDN servers that are deployed at strategic locations within the Internet, which are responsible for storing copies of popular content from the original source. When users request content from the original source they are transparently re-directed to a geographically closer CDN server that has a copy of the media asset. This approach reduces the burden on the original server and also shortens the network delivery path. However, the cost of implementing a CDN is high due to the number of edge servers required. Peer-to-Peer (known as P2P) has emerged as an alternative mechanism for delivering video. P2P is particularly attractive as it represents a scalable solution without the need for additional server support, compared with CDNs - with a P2P solution each device (known as a peer) involved in the communication is capable of acting as both a server and client; thus receiving content and sharing it with others.

However, the ability to deliver videos across parts of the Internet remain a particular challenge. Those on the fringe of the network - such as users of a Community Networks (CNs), are often unable to reliably access streamed media simply because of the resource limitations and external network capacity that is available to them. When considering P2P within CNs for live streaming, the bandwidth restrictions have reduce the probability of successful connections of local clients to other clients that are located outside of the local network. Frequent communication with the remote clients challenges the sustainability of the network and creates a network bottleneck at the backhaul connection. A simple localisation however does not well perform if peer has low capability as this limits number of successful connections. Thus, instead of simple localisation, dynamic locality is introduced in order to counter a network with low peer capability.

Whilst the use of localisation can help there is a secondary issue that relates to the liveness of streamed content; that happen when requested live content is not available. Apart from localisation, an efficient mechanism is needed in order to ensure that the required live content is available at the localised clients. The combination of localisation and the mechanism needs to balance the aims of bandwidth saving and the requirement of preserving the liveness of streamed content.

The rest of this paper is organised as follows: Section II presents the related work and the issues that motivating locality optimisation into P2P live streaming. The OdLoc framework presented in Section III. Section IV discuss the experiments and analysis. Finally in Section V and Section VI we summarise our findings and present our conclusions and further work.

II. Related Works

The implementation of several commercial streaming applications and academic research has highlighted the potential of P2P streaming. Live TV streaming services have been made available to users worldwide, as shown by [5] and PPLive [2]. PPLive uses a P2P-based video distribution protocol for high quality video streaming [6]. According to a study by Hei *et al.* [6], between a campus and a residential peer, a campus peer has more active neighbour peers due to its high bandwidth access network, while a residential network has difficulty in finding sufficient neighbour peers for media streaming, thus forcing it to keep finding new peers. They also find that a

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residential peer has good download ratio locally but prefers uploading streaming content to remote peers. The locality aspect in PPLive is discussed further in [7] however, most of the peers that utilise PPLive were part of the same ISP and so no cost savings could be readily identified. In [8] the NAPA-WINE project discusses optimisation of video delivery and presents a study on the level of network awareness in three P2P applications - PPLive, SopCast and TVants but their findings highlight little or no awareness of location in existing systems.

The study by Wang *et al.* [9] examines locality in P2P video streaming. They criticise the global locality approach, which is based on Autonomous Systems (ASs) and argue it provides no potential for real locality. Instead, due to the effect of clustered peer graph, which can indirectly split the swarm, they consider the use of selective locality mechanisms with localisation based on the size of AS that peer belongs to. The prioritisation of peers is similar; the AS only applies if the AS cluster size is large, otherwise the random strategy is kept. This work supports the idea that a small number of local peers is unlikely to yield improvements in performance.

In the work presented by Liu *et al.* [10], they use the minimum count of AS hops to determine nearby neighbours. Their work involved modifying the neighbour selection, peer choking/unchoking and also piece selection algorithms. Their findings in streaming scenarios conclude that the tracker locality with lowest hop count suffers with unbalanced peer load. In order to address the problem, two different locality strategies are presented. Tracker-based locality is proposed when there is less inter-traffic amongst peers, while choker/unchoker locality is used when priority for reduced playback disruption is selected. The ISP-friendly scheme proposed by Picconi and Massoulie [11] has a randomised two-level overlay: the primary overlay consists of peers in similar ISPs while a secondary overlay consists of inter-cluster links. The secondary overlay promises to provide a backup if piece starvation occurs.

The previously presented work has highlighted the related research carried out in this space, and whilst there has been significant work in reducing the cost of P2P transfers to network providers, typically, this has been for non-sequential bulk transfers and not streamed media. Similarly, work has been undertaken to explore locality in live-streamed media, yet this has typically focused on enabling closeness to live and not considering the bandwidth or cost implications. This paper seeks to consider both aspects: how to reduce the cost of P2P transfers through enabling locality whilst simultaneously focusing on the factors related to closeness-to-live for streamed media. Moreover, other studies have only considered peers that had an adequate upload capacity and had no limitation of connecting to the outside world that reflects the reality of resource-constrained CNs. The evolution of P2P as a file sharing system towards a solution for delivering live video content has sparked significant research interest. The move to live streaming naturally reduces the window during which content is both relevant and interesting to clients as users wish to experience the content as close to live as possible. This introduces several technical challenges, which need to be addressed during the peer selection process - such as selecting not only those peers with the highest capacity but also with an appropriate playback point. Too far in the past and the client will have plenty of data available from other peers, but few will be interested in its content (restricting the sharing and throughput of that client). Similarly, too far in the future and that content will be difficult to obtain and a high demand will then be placed upon that peer.

There are also open questions as to how best to optimise the selection of peers and pieces in order to reduce the delivery costs associated with streamed media, not only for ISPs but also within CNs. Whilst the use of localised peer selection schemes that favour nearby neighbours (such as those within the same network) may result in lower delay and reductions to the amount of cross-traffic they can also potentially lead to performance degradation in some cases. Research by Huang *et al.* [12] aimed to strike a balance between locality and download rate performance. They introduce a Pareto optimal peer selection scheme that considers a desired trade-off decided by the P2P provider. In a different way, Huang *et al.* [13] aim to reduce the lag in playback by trading bandwidth from active peers (stable peers with high contribution). Similar to a super-peer concept, this approach is implemented within an AS. Much of the early work in supporting P2P streaming has focused on the piece selection policy, adapting it to support these additional timeliness requirements. However, this has then highlighted additional issues relating to bandwidth consumption and the 'closeness' to live (also known as the 'hook-in' point).

This paper focuses on these two key issues - firstly, the localisation of peers for live streaming in order to minimise the bandwidth consumed within CNs, and secondly, to optimise the hook-in point. In terms of peer localisation, although many available approaches have been identified this paper focuses on their applicability within CNs. The issue of the hook-in selection policy is an under-explored area and if not well chosen can caused a serious impact on the performance of the P2P system. This paper proposes a novel dynamic hook-in point selection policy in order to balance the range of pieces available for battering amongst the peers within a live P2P system.

III. Optimised Localisation(OpLoc) Framework

Localisation has promoted local communication instead of remote, thus highlight the benefits of reducing the volume of outgoing traffic and saving bandwidth utilisation. However, there are some scenarios of network such as resource limitation that influence the effectiveness of localisation. Thus, in order to have better understanding about localisation impact in such network, we firstly introduce several levels of localisation which has been reported in [14]. Our findings proves that locality mechanisms do provide significant bandwidth savings in live-streaming situations, however there is a strong trade-off between locality and the capability of peers (their available uplink capacity). A reduced client capability results in significantly greater failures with locality enabled than without it.

Results from the experiments highlight the following requirements:

- In restricted AS network, but with high peer capability, client maintains high local connectivity and allows some clients to connect remotely.
- In restricted AS network and peer capability, adjustment to the number of allowable clients that may be permitted to get content from outside and keep remaining client locally. Client potentially fails if it stays local but it is better than failure because it keeps trying to get through the limited AS link.
- In rich AS size, with lower peer capability, client should be downloading from client located externally.
- In rich AS size, and rich peer capability, client prefers staying local by allowing a small number of clients to get content from outside.

In this paper we aim to strike balance between the strong trade-off within a resorce-constrained networks, proposing Optimised Localisation framework (henceforth known as OpLoc). Fig.1 illustrates a set of generic P2P components with the OpLoc framework. OpLoc comprises the following key components: Peer Assessment, Locality Policy and Network Model, which operate at the coordinator side whilst Peer Capability and Local Hook-in reside at the client. The Peer Capability component reports the status of peers to the coordinator; the coordinator processes the locality information based on the Peer Assessment component and the Locality Policy (responsible to group peers based on types of locality enforced) to produce an Network Localisation Index (NLI) value, which is stored in the Network Model component. NLI indicates the level of locality of peers in the P2P. The NLI value determines the percentage of mixture between local and remote peers. For example, with half locality, at least half of the total neighbours are from the local network while the remaining is randomly selected. NLI is introduced as the coordinator function, which appears before local peers are determined. The Network Model then applies the NLI value to the peerlists and associate assetlists in order to produce OpLoc peerlists.

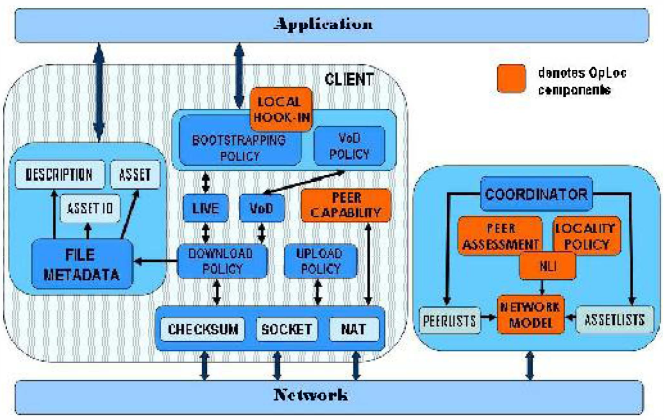

Fig. 1. General P2P Components with OpLoc Framework

A. *OpLoc Framework*

In this paper, the proposed OpLoc Framework consists of dynamic localisation (based on the NLI value) mechanisms and local hook-in point. Thus, dynamic localisation and local hook-in point should able to strike both aims in order to balance the P2P performance. This paper presents a scenario of a resource-constrained network that highlights the limitation in backhaul capacity and peer capability. In such network, local sharing is limits by Peer Capability value whilst remote sharing is limited by the link contention ratio. Internet peers may have high peer capability but cannot serve the local peers due to the limited backhaul link ; obviously this will also result in an increase in bandwidth consumption.

An outline of the OpLoc operations are as follows:-

1) A client contacts a coordinator asking for a peer list.
2) The coordinator calculates the NLI value for the particular local network. The NLI value is calculated based on the local peers capability and also the network contention ratio. There can be more local peers for clients if the peer capability value is sufficient to support local sharing. Otherwise, based on the contention ratio, the coordinator decides if a peer can successfully download from a remote source. If the contention ratio is low and a connection is predicted to fail, the client will prefer to stay local.
3) The coordinator obtains the number of peers based on the NLI value and returns the peer list to the client.

On top of the dynamic localisation, the local hook-in point is another important part of the OpLoc design. The local hook-in point selection corresponds to the modification of the peer selection. Fig.2 shows the steps in defining the local hook-in point. In (i),the coordinator returns the peer list based on the NLI value. Then in (ii), client A determines either to calculate the hook-in point from local peers (example: peer B) or a peer mixture (example: peer B and peer C). The local hook-in point is activated if the number of local peers is at least half from maximum neighbours, otherwise a hook-in point based on mixed local and remote peers is generated. The main reason is to ensure that if the local hook-in point is activated, the number of available local peers is sufficient for maintaining the live playback.

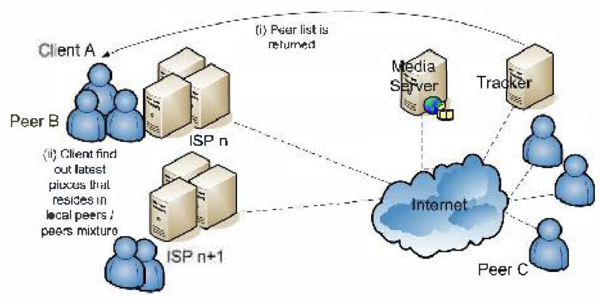

Fig. 2. Local Hook-in Point Design

IV. Experimentation and Analysis

The aim of our experimental analysis was to determine the impact of optimised locality and local hook-in on a live streaming P2P system. We defined two simulation set ups, mimicking two network environments. The first (Scenario 1), a corporate or community network in which internal connectivity between peers is high, secondly (Scenario 2) an ADSL style connection in which the upload capacity of each peer is poor. For both scenarios we define four different contention ratios (AS20, AS50, AS220, AS440), the value represents the maximum simultaneous pieces than can traverse the Internet transit at any one time. In each simulation there are four networks - three which represent end networks (e.g. ISPs) and one network which represents the public Internet. The AS capacity restrictions are only placed on the three ISP networks and not the link to the general Internet (which is unlimited). In this experiment, we define the peer connectivity rules that based on the successfulness of each connection. The remote connection from a local network depends on the AS maximum connection. A connection fails if an excessive number of requests is made of the AS maximum connection. On the other hand, the local connection among peers is considered resource-rich, thus there is no restriction on the connection among local neighbours. In both cases, if a connection is successfully made, the probability of successful download is dependent on the upload capability of the neighbours. In the case of a neighbour which has low upload capability and is fully used, then the download process is considered to failed.

In the OpLoc design, we considered the probability of success in remote and local connection as a guideline in determining the level of localisation. At first, the number of available local peers is obtained. If no local peers are available, then the NLI value is automatically set to random. Otherwise, the probability of success of local and remote connections is determined. The probability success of local connection is based on the formula of single event probability (Equation 1).

$$P(localsuccess) = \frac{n(no.oflocalsuccess)}{n(no.ofpeerfromlocal)} \quad (1)$$

The successful connection among local peers are highly depending on the peer capability. The probability value of local success indicates the number of local peers that is potentially successful to be served locally. For example, if *P(local success)* value is 0.2, then 20% from local peers can be served among each other locally, while other 80% is remote peers.

A. Playback Point Consistency

In Scenario 1, plenty capability among local clients enables each of them to supply content among each other. Fig.3 shown how high peer capability helps in supporting locality which allow only a small fraction of clients to download remotely, while others exchange content locally. Each client is able to preserve its live playback although in highly contended AS link (Fig.3(a)).

Contradicted to Scenario 1, Scenario 2 has lacks peer capability that potentially harms the overall performance of the P2P network. Graphs shown in Fig.4 highlight the playback continuity and consistency through OpLoc in Scenario 2. In Fig.4(a), the restriction of AS link has made a big impact on playback continuity. Most peers are moving away from live resulting from high failure because of high competency in getting through the limited AS link. Both restrictions impact the download performance and thus affect the playback, resulting in most failures due to limited AS capacity. The increasing of AS link size has shown remarkable improvement as indicated in Fig.4(b), and most of clients now are able to cope with live. However, some clients at tick 400 are starting to move away for reasons of peer capability, which is expected (shown in Table I).

B. Bandwidth Utilisation

OpLoc positively helps in bandwidth utilisation reduction in most AS network sizes. Fig.5 highlights the usage of bandwidth in Scenario 1 with OpLoc and Fig.5(b) with AS size 220 particularly. In comparison of bandwidth consumption between Fig.5(b) and Fig.6(b), OpLoc has significantly save more bandwidth in Scenario 1. This support the decision of peers in favouring local peers as their capability is high. On the other hand, in Scenario 2, in order to preserving playback, peers sacrifice their bandwidth to communicate with the remote peers due to the low peer capability.

Table I details the reasons for failure that occur with OpLoc. In both scenarios, the majority of failure are due to peer capability. Although they have a similar percentage, the number of failures is excessive in Scenario 2. Failure due to AS capacity only occurs when an AS link has limited bandwidth. Hence, OpLoc has eliminated the failure of seed capability by enhancing the level of sharing between clients.

In Scenario 2 that has rich AS link size, failure also occurs due to low peer capability. As OpLoc is primarily concerned with preserving live playback and saving bandwidth, such failure is unavoidable. OpLoc only allows a fraction of local clients to obtain fresh content while the remainder stay local. Thus, failure is likely to happen when most of local clients are trying to get content from the same local clients that has fresh content.

TABLE I
Reason for Piece Failure: OpLoc

	No Piece	Peer Cap.	Seed Cap.	AS Cap.
Scenario 1				
AS20	11.97%	62.28%	0%	25.75%
AS50	0%	100%	0%	0%
AS220	24.44%	75.56%	0%	0%
AS440	4.29%	95.71%	0%	0
Scenario 2				
AS20	1.73%	64.83%	0%	33.44%
AS50	0%	99.04%	0%	0.96%
AS220	0%	100%	0%	0%
AS440	0%	100%	0%	0%

V. Discussion

As mentioned in [14], there is a strong trade-off between the live playback and bandwidth reduction, especially in a resource-constrained network scenario. It is because to save more bandwidth, clients need to select most of neighbours that are located locally over external to them. However, with a limited local peer capability, this is not a solution as local peers are incapable of performing the upload process. Thus, failure is likely to frequently happen if locality is enforced in such network conditions. One simple solution is to let the local peer download content from the external sources but this action increases the number of cross-traffic at the Internet transit. We proposed OpLoc in order to counter the strong trade-off between the live playback and bandwidth reduction.

There are two main components in OpLoc - dynamic locality and local hook-in point. Our first approach in [14] was to introduce different locality level to the P2P network in order to study the impact of the differences to the network. Our findings show that in Scenario 1, with high internal connectivity among peers, pure locality does reduce the bandwidth consumption at the Internet transit and manages to maintain the playback point towards live. However, with poor internal connectivity, local peers sacrifice the playback in order to have pure locality in place. This indicates that pure locality only works in a network that has high internal capacity. Introducing local hook-in point on top of locality has significantly highlighted some positive findings as follows:

- In a scenario that has low internal capacity, only random peer selection manages to maintain live playback but sacrifices network bandwidth.
- In a scenario with high internal capacity, locality and random selection works perfectly.

Considering these findings, we highlight the role of OpLoc in introducing 1) dynamic locality based on the network limitation, AS capacity and peer capability and 2) local hook-in point. OpLoc is responsible for obtaining the ideal NLI value that can strike a balance between bandwidth reduction and playback point continuity.

In low capacity AS links, only a limited number of clients are allowed to pass through. Although in large size AS link, OpLoc tries to be as local as possible and allows only some required number of external connections in order to preserve piece availability locally, others keep communication locally. OpLoc finds out the required number of clients needed to get new content in order to support demand from local network. Thus, OpLoc keeps communication as much local as possible while at the same time reduces download failure that affects playback continuity. OpLoc has successfully managed to keep live playback point and reduce bandwidth utilisation to an acceptable level through dynamic localisation.

VI. CONCLUSION

This paper has presented the design and development of dynamic localisation and local hook-in support (OpLoc) for P2P platforms. The idea of dynamic localisation has emerged as a result of an analysis of general localisation approaches which can negatively impact the performance of P2P content distribution, particularly within resource-constrained networks. The concept of local hook-in support is designed to preserve the continuity of live playback within resource-constrained networks, whilst also balancing the bandwidth requirements associated with P2P distribution. The concepts that have been presented within this paper are designed for delivering streamed content in a resource-constrained network - with a limited network contention and low peer capability. OpLoc consists of two modules; dynamic localisation and local hook-in. While dynamic localisation reduces failures in content download, the local hook-in preserving the 'liveness' playback at peers. For future work, we aim to study other available types of network for wider implementation of OpLoc framework and investigate different types of network limitation such as bottleneck, and delay.

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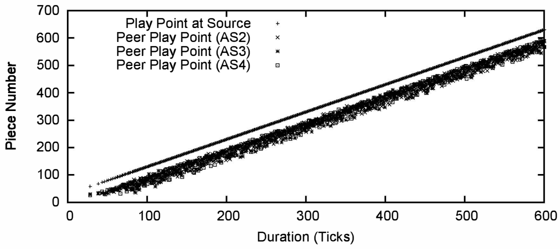
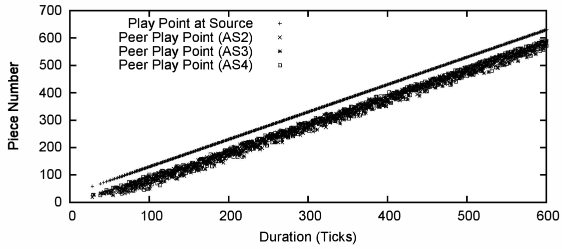
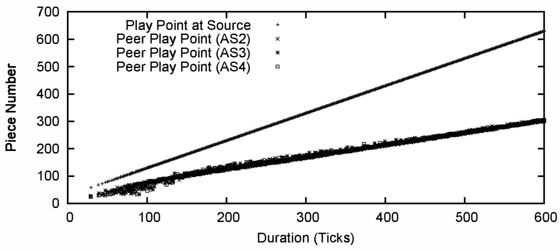


(a) AS Capacity of 20



(b) AS Capacity of 220

Fig. 3. Scenario 1 : Average Playback Point - OpLoc



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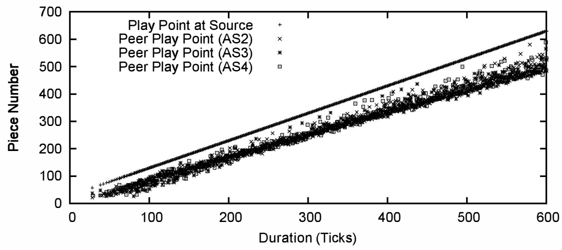
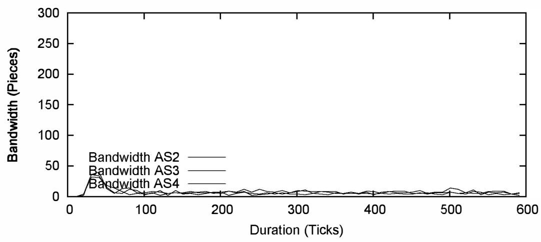
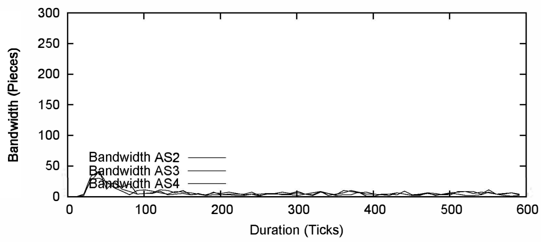


(b) AS Capacity of 220

Fig. 4. Scenario 2 : Average Playback Point - OpLoc

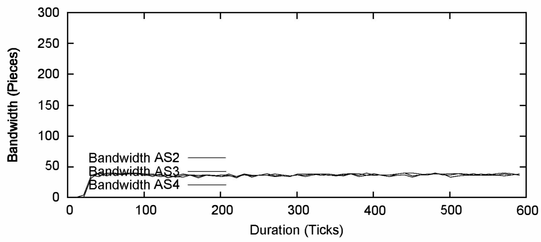


(a) AS Capacity of 20

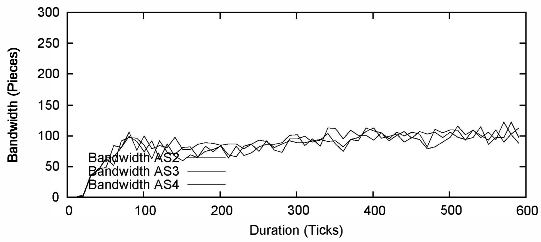


(b) AS Capacity of 220

Fig. 5. Scenario 1 : Bandwidth - OpLoc



(a) AS Capacity of 20



(b) AS Capacity of 220

Fig. 6. Scenario 2 : Bandwidth - OpLoc