SOLTA - A Service Oriented Link Triggering Algorithm for MIH Implementations

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ABSTRACT
The emerging Media Independent Handover (MIH) standard proposes to support session continuity during handover between heterogeneous networks. One of the critical features provided by MIH is an Event Service which includes predictive network degradation events, such as Link_Going_Down (LGD), which are triggered based on link layer metrics. Our results highlight the reactivness of media stream quality to network degradation. The point of degradation however, is specific to the characteristics of the class of media streaming service. Many existing event algorithms utilize static performance thresholds which are unresponsive to the requirements of individual application service classes. In this paper we propose a Service Oriented Link Triggering Algorithm (SOLTA) which triggers the LGD and Link_Down (LD) events based on link layer metrics but subject to the performance characteristics of the supported class of service. SOLTA illustrates that for 802.11, it is necessary to have aggressive service class specific, link event triggering. SOLTA also illustrates how a soft path handover approach such as Stream Control Transmission Protocols Concurrent Multi-path Transfer (SCTP-CMT) variant is necessary to support seamless session migration.

Categories and Subject Descriptors
C.2.1 [**Network Architecture and Design**]: Wireless Communication; C.2.2 [**Network Protocols**]: Routing Protocols

General Terms
Theory, Performance.

Keywords
Adaptive media-streaming, MIH, link events, mobility.

1. INTRODUCTION
MIH, from the IEEE's 802.21 working group[1] is an emerging standard which supports seamless handover between homogenous and heterogeneous networks. MIH does not in itself implement network handover; rather it provides a framework to allow handover to and from a range of networks including 3G, HSDPA, Bluetooth, WiFi and WiMax.

Within MIH there are events which are used to control service adaptation and network handover. One of the most critical, is the LGD event which is triggered based on an analysis of link layer performance metrics. While MIH defines the primitives to configure the LGD event, the event triggering algorithm is implementation specific. Many existing Event Service implementations utilize a coarse grained link layer performance threshold P_{thres}, typically based on Received Signal Strength (RSS), to generate the LGD event [2][3][4]. The prediction interval, the time between the LGD and LD events, is configured around P_{thres} using a anticipation factor parameter $\alpha_{\lg d}$. Such approaches are performance limited as P_{thres} is based on the characteristics of the network, without regard to the requirements of the supported service class. These performance limitations arise as application classes can have (a) different points of performance degradation in the same network conditions (b) different requirements with respect to the time interval required between the predictive event, LGD, and reactive event, LD.

In this paper we propose SOLTA which adaptively triggers the LGD and LD events based on link layer performance metrics but subject to the performance characteristics of the supported class of service. We enhance the interface between the MIH Function (MIHF) and the MIH Event Service to define the application service class and the level of prediction required for the LGD event.

Within SOLTA we propose the introduction of a dynamic performance threshold $P_{adapt-thres}$ which is configured with regard to the QoS requirements of the supported service. We analyze the optimal configuration of $\alpha_{\lg d}$ which is a tradeoff between (a) aggressive LGD triggering, in which the excessive delay between the LGD and LD events could result in changed alternate path conditions (b) passive LGD triggering, in which the packet loss during switchover results in service disruption. We estimate network degradation for various application classes and anticipation factors using variants of the moving average algorithm. Our results suggest that link triggering algorithms for 802.11 should limit the potential for (b) by reacting very aggressively to network degradation. Our results also show that the limited time between LGD and LD for 802.11 requires a soft handover strategy which we implement using a variant of Stream Control Transmission Protocols Concurrent Multi-path Transfer (SCTP-CMT). This approach enables stream adaptation on the alternate path prior to handover.

2. Related Work

A number of studies have investigated the optimization of the MIH LGD event. Most implementations are based on pre-defined thresholds, mostly associated with RSS. If the current RSS crosses a predefined threshold P_{thres} the LGD event is generated [2][3]. Other solutions [4][5] use a predictive model which uses the neighbor information to generate timely link triggers so that handover procedures can finish before the link goes down. Such approaches are unaware of the supported application class and still use a static P_{thres}. In [6] Seamless Wireless internet for Fast Trains (SWiFT) is proposed, which relies on a fast handoff using L2 triggering and a handover probability value evaluated using RSS. Our results indicate that as media streaming quality is extremely reactive to network degradation, in particular delay, RSS may not be sufficiently proactive to identify degradation of the link.

Since the MIH framework does not in itself implement network handover it relies on a mobility protocol such as SIP, MIP or SCTP. Given the "break before make" approach utilized by MIP a number of studies have investigated the optimization of MIH messaging in order to limit candidate network discovery time as well as L2 and L3 handover. In [7] handover profile and entrusting messages are introduced to allow the serving PoA to access each user's handover policies without any requests for handover information to MN. In [8] an extension to MIH is proposed in which QoS provisioning of the target network occurs during the handover preparation phase. In [9] a solution for vertical handover of a multimedia session based on SIP with the triggers being provided by MIH is proposed. We present results which illustrate that the reactivness of media stream quality to network degradation requires a "make before break" approach to limit handover disruption. We introduce a variant of SCTPs CMT technology to initiate, transmit and adapt a variant of the stream on the alternate path prior to network handover.

3. Media Independent Handover

MIH is an emerging IEEE standard which supports seamless handover between homogenous and heterogeneous networks. MIH does not in itself implement network handover, rather it provides information to allow handover to and from a range of networks. The network handover enabling function within the protocol is implemented through the MIH Function (MIHF). MIHF consists of 3 elements, the event service, command service and information service.

The event service will typically be used to detect need for handovers. For example an indication that the link will cease to carry MAC SDUs at some point in the near future. This has the potential to reduce the time taken to handover between attachment points. The command service enables higher layers to control the physical, data link and logical link layers. The higher layers control the reconfiguration or selection of an appropriate link through a set of handover commands. The commands carry the upper layer decisions to the lower layers. Media Independent Information Service (MIIS) provides a framework and corresponding mechanisms by which a MIHF entity may discover and obtain network information existing within a geographical area to facilitate the handovers. MIIS primarily provides a set of information elements (IEs), the information structure and its representation and a query/response type of mechanism for information transfer.

4. A Service Oriented Link Triggering Algorithm

In this section we outline SOLTA which triggers the LGD and LD events based on link layer metrics but subject to the performance characteristics of the supported class of service. Many existing MIH implementations use the following approaches (a) pre-define a threshold level, P_{thres}, when the performance metric, usually RSS, exceeds this limit raise the LGD event (b) pre-define threshold levels and use α_{lgd} to define link triggering aggressiveness around P_{thres}. Equation (1) expresses the relationship between the time, $T_{\deg}$, at which P_{thres} (actual or projected) is exceeded and the time at which path handover is initiated, T_{h-init}.

$$T_{h-init} = \alpha_{\lg d}(P_{thres}) \quad (1)$$

Figure 1 illustrates how such a relationship is dependent on the rate of wireless degradation.

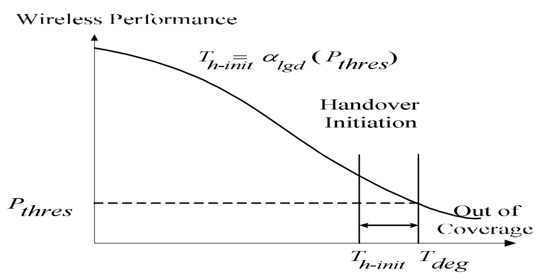

Figure 1. Handover Initiation Based on T_{deg}

We will see that such approaches are inappropriate when streaming media since application classes can have vastly different points of performance degradation in the same network conditions. We propose the introduction of a dynamic performance threshold $P_{adapt-thres}$ which is configured with regard to the application service class. Figure 2 illustrates how such an approach can optimize the triggering of the LGD event based on wireless degradation. Equation (1) then becomes:

$$T_{h-init(servicetype)} = \alpha_{\lg d}(P_{thres(servicetype)}) \quad (2)$$

Figure 2 illustrates how $P_{adapt-thres}$ can be used to adapt $T_{\deg(servicetype)}$ and $T_{h-init(servicetype)}$.

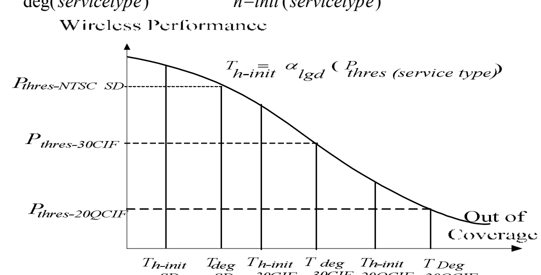

Figure 2. Handover Initiation Based on $T_{deg(service\ type)}$

Equation (3) defines $T_{Adaption}$, the time taken for a media streaming session to adapt following a MIH controlled path switchover.

$$T_{LGD} + T_{Discovery} + T_{Selection} + T_{L3HO} + T_{L2HO} + T_{StreamAdaption} \quad (3)$$

T_{LGD} is the time taken to generate the LGD event, $T_{Discovery}$ the time to identify candidate networks, $T_{Selection}$ the time to select a suitable path from the set of candidates, T_{L3HO} and T_{L2HO} the time taken to implement Layer 3 and Layer 2 handover and $T_{StreamAdaption}$ the time taken to adapt the media stream to the changed network conditions. Many existing MIH implementations utilize MIP which implements a "break before make" approach to network handover. By using the multi-homing features of SCTP it is possible to implement a "make before break" approach. If we assume the existence of a preconfigured alternate path we can disregard the network discovery and selection components as well as the Layer 2 handover component. Equation (3) is therefore reduced to:

$$T_{Adaption} = T_{LGD} + T_{L3Hanover} + T_{StreamAdaption} \quad (4)$$

Equation (5) describes the optimal configuration of the anticipation factor.

$$\alpha_{lgd}(T_{\deg(servicetype)}) \approx T_{LGD} + T_{L3Hanover} + T_{StreamAdaption} \quad (5)$$

In order to enable the streaming applications to define their service class and anticipation factor we update the MIH LGD service primitive as follows:

Link_Going_Down.indication (LinkIdentifier, χ, α, ConfidenceLevel, ReasonCode, UniqueEventIdentifier)

χ defines the service class and α is the anticipation factor. For each link layer performance metric we scale its value x on a range of 0, best performance, to 100, worst performance as follows:

$$y = \frac{x - x^{\min}}{x^{\max} - x^{\min}} \quad (6)$$

In order to estimate performance trends and eliminate outlying values for the scaled metrics we evaluate the performance of variants of the moving average algorithm:

$$y'_k = \beta y_{k-1} + (1-\beta) y'_{k-1} \quad (7)$$

$$y'_K = \left(\sum_{k=1}^{n} y_k - \max(y_n) - \min(y_n) \right) \frac{1}{n-2} \quad (8)$$

In Equation (7) we implement the exponential weighted moving average algorithm which applies weighting factors which decrease exponentially for older input values. The degree of weighing decrease is expressed as a constant smoothing factor β, a number between 0 and 1. In Equation (8) we apply the Olympic moving average algorithm which removes the high and low values of data set and averages the remaining values. For this algorithm we evaluate varying historic set sizes through the configuration of n. We use the class of service χ to define the level of smoothing, β for Equation (7) and n for Equation (8). In later sections we will illustrate how the level of smoothing can be used as a coarse grained indicator of service class. The LGD event is then triggered when $y'_K > \alpha$. The operation of the SOLTA algorithm is described as follows:

```
Routine::Link_Going_Down.indication(LinkID,
service_class, anticipation)
  var smoothing = calculatesmoothing(service_class)
  var perfthreas = calcperfthreshold(anticipation)

Routine::Generate_LGD()
  for each performance metric
    var currentPM = getPMValueFromMAC()
    var scaledPM = scalePM(currentPM)
    var smoothedPM = movingaverage(scaledPM)
    if(smoothedPM > perfthreas)
      generate LGD_Event

Routine:: movingaverage (scaledPM)
  var oldSmoothed = newSmoothedValue
  var newSmoothed
  newSmoothed =
    smoothing *scaledPM + (1- smoothing)* oldSmoothed
  return newSmoothed

Routine::scalePM(PMValue)
  static var minPMValue
  static var maxPMValue
  return PMValue-minPMValue/ maxPMValue-minPMValue
```

5. An Analysis of 802.11 Performance Degradation

In this section we analyze the performance of wireless networks in order to determine the relationship between P_{thres} and $T_{\deg}$ for various media streaming service classes.

5.1 An Evaluation of 802.11 Performance Metrics

An experimental test configuration was created which consisted of two nodes representing a Mobile Node (MN) and a Corresponding Node (CN) connected by a Linksys WRT54GL 802.11g access point. Both laptops were configured with SCTPLIB [10]. The MN used Wireshark with AIRPCAPs 802.11 plug-in for wireless packet capture. The MN also used Netstumbler to record wireless signal strength. The test started with the MN adjacent to the access point. The MN then moved at slow walking pace away from the access point. We selected a sample test for further investigation.

While MIH defines the interface between the Event Service and MIHF the algorithm used to generate the LGD event is implementation specific. We analyzed the following wireless performance metrics; RSS, loss rate and delay. Using Equation (6) we scale our experimental recorded values. For RSS we define the performance boundaries to be -10dBm to -90dBm. For delay we define the boundaries 0 to 500ms. Figure 3 illustrates the behavior of these performance metrics over the duration of the test.

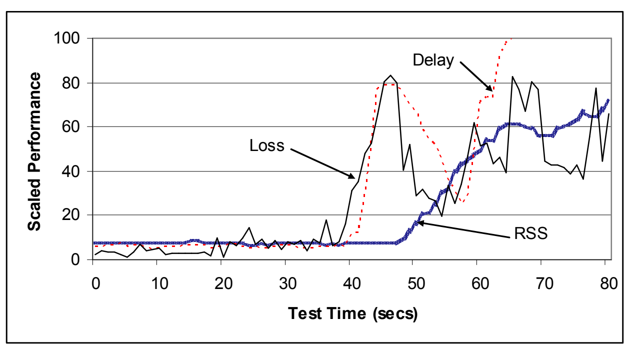

Figure 3. 802.11 Performance Metrics

Studies have indicated the existence of a point of significant performance degradation in 802.11[11][12]. This point of performance degradation is particularly detrimental when the 802.11 MAC utilizes a drop tail queue. As network conditions degrade, loss rates increase causing buffer congestion. In a drop tail configuration, there is a sudden and significant increase in loss as the buffer reaches maximum capacity. While each performance metric indicates this degradation, the loss and delay indicate it occurs initially at approx 40 seconds while RSS degradation does not occur until approx 50 seconds. The limitations of RSS as a performance indicator are discussed more fully in the following section.

5.2 An Analysis of Media Streaming Performance with Wireless Degradation

In this section we analyze $T_{\deg}$ for various media streaming service classes. We create a simulation model which uses our NS2 framework, Evalvid-SCTP [13]. Evalvid-SCTP enables the simulation of multimedia streaming over Partially Reliable SCTP(PR- SCTP) based on the generation of MPEG-4 video trace files. Using Evalvid-SCTP we analyze $T_{\deg}$ for a 2000 frame video sequences with CIF and QCIF resolution and frame rates of 25, 20 and 15 Frames Per Second (FPS). We initially configure a single wireless path using the performance metrics from Section 5.1. Figure 4 illustrates the PSNR calculated for the 2000 frame video sequences.

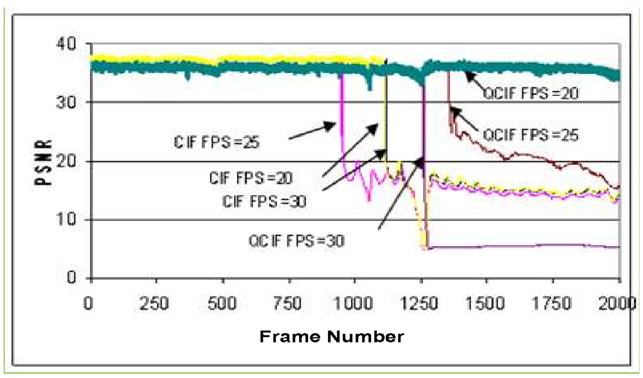

Figure 4. PSNR for Media Stream Configurations

Figure 3 illustrated a point of significant performance degradation at 40 seconds. Figure 4 illustrates that classes of service react differently to the underlying network degradation. Five of the six configurations illustrate a point of significant performance degradation. The low bandwidth requirements of QCIF at 20FPS allow it to function even on a degrading path. The higher bandwidth requirements of CIF result in an earlier point of media stream degradation; the degradation occurred following the transmission of frames 1115 (37.16sec), 953 (31.76sec) and 1112 (37.06sec) for frame rates 30, 25 and 20. The lower bandwidth requirements for QCIF allow more time for stream adaptation between network degradation and stream degradation. For QCIF the degradation occurred following the transmission of frames 1260 (42.0 sec) and 1358 (45.26sec) for frame rates of 30 and 25 FPS respectively.

5.3 Optimizing the Anticipation Factor for Service Classes

In this section we optimize the selection of $\alpha_{\lg d}$ as in Equation (5) for the service classes illustrated in Figure 4. The optimal configuration of $\alpha_{\lg d}$ is a tradeoff between (a) excessive aggressiveness, in which the delay between the LGD and LD events could result in changed alternate path conditions (b) excessive passiveness resulting in long service disruption from packet loss during switchover.

Many existing solutions utilize RSS as the indicator of path performance. While RSS provides a coarse grained view of performance, it does not consider the dynamic performance characteristics of the network path. Figure 4 indicated that the media streaming services experienced degradation from as early as 31.76secs. Figure 3 indicates that RSS did not degrade significantly until 50secs. In this scenario it is not appropriate to utilize RSS in the switch decision as even the least demanding service, QCIF at 25FPS, experienced performance degradation at 45.26 secs. We therefore base our algorithm on link layer delay and loss rates.

Figure 3 and Figure 4 illustrate that the media streaming quality is very reactive to underlying network performance degradation. The smoothing parameters must therefore be very reactive to degrading performance. In effect this requires large β values for Equation (7) and small values of n for Equation (8). Figure 5 illustrates the effect of performance smoothing on the loss rate for $\beta = 0.9$ and $n = 3$.

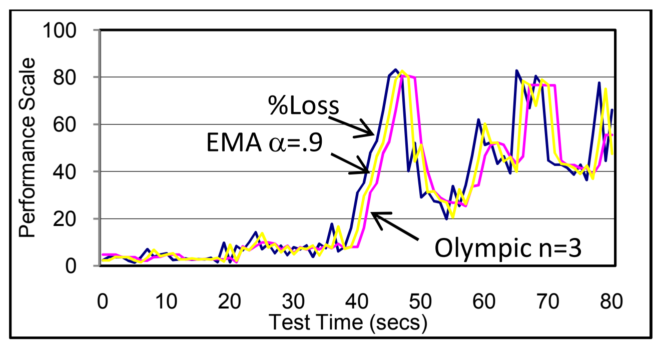

Figure 5. Loss Performance Scale Smoothing

Figure 5 illustrates that Olympic smoothing is inappropriate as the minimum value of n=3 results in smoothed values which do not have the necessary reaction to performance degradation. We therefore select the EMA approach as β can be configured with fine granularity. Our results illustrated that delay as a performance indicator is relatively static up to 40 seconds and then degrades acutely. Its usefulness is therefore limited in the prediction of performance degradation. The loss performance does indicate degradation of the path over time, its performance scale drops to 14 at 25 seconds and to 17 at 37 seconds.

Equation (4) indicated that the total time required for adaptation, $T_{Adaption}$ consisted of path switchover delay, LGD event triggering delay and the time required to adapt the media stream on the alternate path. If we assume $T_{Adaption}$ is 5secs, then the following are the conditions for selecting the optimal β for particular media stream classes (a) largest β such that $T_{LGD} < T_{LD}$ – 5secs (b) smallest β such that $T_{LD} < T_{\deg(servicetype)}$. Table 1 describes the LGD and LD triggering times for α and β configurations.

Table 1. LGD Time/LD Time for α and β Configurations

	β=.9	β=.7	β=.3	β=.1	β=.05	β=.01
α =12%	19/36s	23/40s	24/40s	36/42s	43/47s	50/69s
α =10%	24/36s	24/40s	36/40s	40/42s	44/47s	56/69s
α =8%	24/36s	24/40s	40/40s	41/42s	45/47s	62/69s
α =6%	36/36s	36/40s	40/40s	42/42s	46/47s	66/69s

In Section 5.2 we indicated that the times of performance degradation for CIF resolution with frames rates of 30, 25 and 20 were 37.16, 31.76 and 37.06 secs respectively. We therefore suggest the values β = 0.9 giving a LD time of 36 secs and α = 8% allowing 12 secs for configuration of the alternate and media stream adaptation on the alternate. For QCIF with FPS = 30 the degradation occurred at 42.0 secs we therefore suggest β =0.1 giving a LD time of 42 secs and α = 12% giving an LGD time of 36seconds. For QCIF with FPS = 25 the degradation occurred at 45.26 secs we therefore suggest β =0.1 giving a LD time of 42 secs and α = 10% giving an LGD time of 40seconds. Finally for QCIF FPS = 20 no degradation occurred in the timescale of the test we therefore suggest β=0.01 and α=8% as the optimal configuration.

In order to evaluate the LD and LGD times suggested by SOLTA we updated the simulation configuration described in Section 5.2 to include an alternate path configured with HSDPA characteristics; 3.6Mbps and a uniform 3% loss rate. Figure 7 illustrates the PSNR ranges for the CIF and QCIF resolutions utilizing the SOLTA switch times.

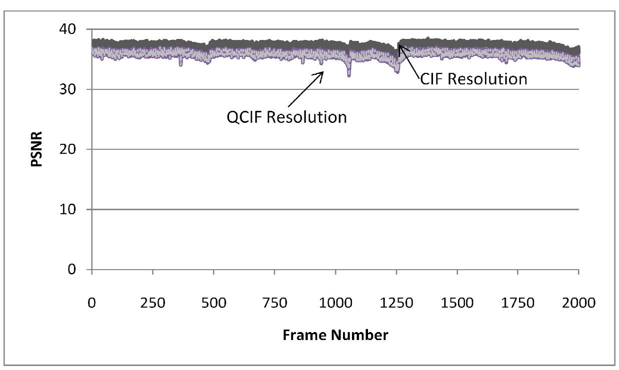

Figure 6. CIF and QCIF PSNR Ranges with SOLTA Path Switchover

Figure 4 illustrated that the CIF based formats experienced significant performance degradation at 37.16sec, 953 31.76sec and 37.06sec for frame rates 30, 25 and 20. For QCIF formats using 30 and 25 FPS the performance degradation occurred at 42.0 sec and 45.26 sec respectively. Figure 6 illustrates that the SOLTA algorithm interprets the point of sudden wireless degradation indicated in Figure 3 and generates the LGD going down event allowing sufficient time for media stream adaptation on an alternate path. Table 1 however indicates that in order for SOLTA to be effective for higher bandwidth formats such as CIF at 30FPS it must be very aggressive, β = 0.9, when triggering the LGD event. β = 0.9 gives a 9:1 precedence to the current performance metric value over previously smoothed values.

6. Conclusion and Future Work

In this paper we presented SOLTA which triggers the LGD and LD events based on link layer metrics but subject to the performance characteristics of the supported class of service. Our results highlight the reactivness of media stream quality to network degradation. The point of degradation however, is specific to the characteristics of the class of service. SOLTA illustrates that in order for MIH link triggering algorithms to be capable of supporting real time sessions they must define specific service classes and react aggressively to network degradation. For 802.11 the limited time between LGD and LD also requires a predictive soft handover strategy such as SCTP-CMT.

Future work will focus on the optimization of the SOLTA algorithm for metropolitan wireless networks.

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