Enhancing Mobile E-Witness with Access Point Selection Policies

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Abstract

This paper describes the Mobile E-Witness (MEW) surveillance system which we have extended to incorporate in it an advanced access point selection mechanism. The mechanism selects dynamically the best access point among those reachable in the metropolitan areas where MEW operates. The selection policy is based on both the strength of the access point’s signal and the traffic on the wireless communication channels. The selected access points are associated with the wireless network adapters available on board of MEW Mobile Sensor devices, thus allowing these devices to reliably and continuously transmit multimedia data streams to a remote storage center for future replay. We have carried out an experimental evaluation of the extended MEW prototype in order to assess its effectiveness in coping with such limitations as scarce wireless communication resources. The results of this evaluation are discussed in this paper and show the adequacy of our approach.

Key Words – Access point selection, resource-intensive multimedia applications, wireless communications, multi homing, mobile sensor

1. Introduction

Nowadays, cities like Bologna and Genoa in Italy, and Chicago [7] in the US deploy their own wireless networks in order to allow their citizens to be always “on-line”. Owing to these realities, we have recently developed a prototype system named Mobile E-Witness (MEW) [2] that can be used for scopes of surveillance in metropolitan areas. MEW enables the acquisition and remote storage of multimedia (i.e., audio and video) data streams. In MEW, a mobile device termed Mobile Sensor (MS), incorporating a micro-camera, a microphone, and two or more wireless adapters, can be “worn” (i.e., it can be carried without causing any impediment) by public officers such as policemen and health care workers in order to record the events these officers witness while on duty. MEW transmits these events to a remote storage center termed Control Center (CC) for future replay (see Figure 1). Events recorded by MEW can be then used as an impartial testimony to resolve possible disputes concerning the relative responsibilities of the participants to that event (including the officers themselves).

In order to collect and transmit multimedia data the MS exploits the wireless hotspots (and the wired communications behind them) that can be (i) available in local areas, (ii) either privately or publicly owned, (iii) independently managed, and (iv) based on wireless technologies conformant to the 802.11b and 802.11g standards. When an operator walks around the city, his/her MS selects dynamically the most effective communication service in each area, guaranteeing the continuity of the communications between the MS and the remote CC, as shown in Figure 1. Specifically, different Access Points (APs) are selected and associated with each MS wireless adapter, so as to effectively use different paths with the remote CC.

Figure 1. MEW system architecture

This wireless scenario typically suffers from such limitations as scarce communication resources in terms of bandwidth provided by each AP, and lack of continuity of the communications between APs and mobile devices. Those limitations can be exacerbated in the specific metropolitan scenario in which multiple obstacles can reduce the transmission range, and a large number of concurrent users can consume the available bandwidth.

Owing to these observations, the MEW system has been designed to overcome the typical resource constraint issues of a wireless environment. As shown by our evaluation [2] in a metropolitan area (i.e., Bologna city in Italy) we have been able to achieve the following four principal results: MEW 1) tolerates temporary disconnections with the wireless AP so as to guarantee highly available communications, 2) ensures sufficient bandwidth for multimedia data transmission, 3) limits, within a few seconds, the maximum elapsed time between the acquisition of each audio/video frame and the storage of that frame to the remote CC, and finally 4) limits the power consumption of the MS transmission so as to reduce the electromagnetic radiations absorbed by the human operator.

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1 This work has been partially funded by the strategic project of the University of Bologna entitled “Enabling Services On Vehicles (ESOV)” and ELSAG DATAMAT.
However, the MEW design described in [2] exhibits a principal shortcoming that prevents the system to fully face the resource limitation issues that emerge in wireless environments. Specifically, this shortcoming concerns the MEW AP selection phase, which allows MEW to associate an AP with a given MS wireless adapter. The MEW (and common) AP selection criterion is based on the perceived quality of the communication link between the MS and a given AP. The quality of the link is an aggregate value that depends on the driver and hardware used. The driver determines the quality of the link based on a number of factors including the level of contention or interference, the bit or frame error rate, the strength of the received signal (i.e., Received Signal Strength Indicator, RSSI), possible timing synchronizations, and other hardware metrics.

Selecting the best AP based only on the link quality cannot be sufficient to deal effectively with wireless resource constraints, especially in a scenario such as that described earlier. In fact, an AP with a good link quality might not be the best choice if that AP suffers from a high traffic level, as the available bandwidth may not be sufficient to send the collected multimedia data.

In this paper we describe how to enhance the MEW system with a different AP selection policy. For this purpose, a further component is added to the MEW architecture; this component is named Access Point Monitor (APM); it operates at the MS side only, and it is able to dynamically select the best AP under short time limits using a combination of metrics: those related to the strength of the received signal and, in particular, those related to the traffic interference. This paper focuses on the design of the APM, and on the implementation and experimental evaluation of the MEW system extended with the APM. The experimental evaluation shows that the enhanced MEW can deal effectively with issues of resource constraints in metropolitan wireless environments.

This paper is structured as follows. The next section summarizes the standard WLAN behavior in selecting APs and its limits. Based on this analysis, section 3 describes the APM design model. Section 4 discusses the MEW architecture extended with the APM, and section 5 introduces the principal results we have obtained from an experimental evaluation of this architecture. Section 6 discusses some related works and, finally, section 7 concludes this paper.

2. WLAN background

As of today, the majority of WLANs are based on the IEEE 802.11 standard. In the 802.11 standard, a mobile station (STA) has to firstly select (and associate with) an AP before it can access to data transmission services of the WLAN cell. Specifically, the STA tries to associate with the AP with the highest signal strength due to the rate adaptation mechanism (named multi rate protocol) of the 802.11’s physical layer of the STA. This mechanism allows the STA to tune its transmission rate in response to the quality of the wireless link to the AP. If the quality of the link is poor the STA requires more robust modulation and coding schemes that reduce its actual transmission rate. In contrast, associating with the AP that exhibits the highest signal strength means that the STA can communicate at the highest transmission rate.

However, the traditional STA access point selection mechanism, based on the strength of the received signal, may not be appropriate when it is crucial to select the AP that provides a large amount of bandwidth; moreover, such traditional policy may lead to poor user-perceived performance and highly unbalanced load distribution [1]. Thus, a wider set of parameters (some related to the signal strength, others independent from it) needs to be considered, as it may impact the service provided by an AP. We summarize these parameters below.

Maximum transmission rate allowed by an AP: it depends on the hardware of both an AP and a given STA, and represents the upper bound to the transmission rate used in the communications between a STA and its relative AP.

Actual STA average transmission rate: this parameter represents the average transmission rate used in the communications between the AP and its relative STA. It principally depends on the link quality; the worse the link quality, the lower the actual transmission rate (lower transmission rate means decreasing both the loss rate and the need for retransmissions). This parameter strongly impacts the channel occupation introduced below.

Channel occupation: this parameter represents the percentage of the total time in which the channel is used by the communication between an AP and its relative STA. The channel occupation depends on both the traffic produced/received by STAs and the rate used for that traffic transmission. In fact, a STA that transmits at a low rate occupies the channel for a time interval which is longer than that required by a high rate STA.

Channel interference: it represents the interference level that affects a given AP, it can be caused by different external sources, which include other APs. The interference depends on the signal strength of APs and their STAs.

To conclude, it is worth noticing that owing to the contention mechanisms for the transmission in the IEEE 802.11 environment, increasing the traffic that can affect a given AP leads to increase the waiting time necessary before the transmission, thus decrementing the responsiveness of the AP.

3. Access Point Monitor Design

We have designed the Access Point Monitor (APM) and deployed it in a given MEW MS in order to allow that MS to select the best AP based on the knowledge of the its surrounding environment. This knowledge includes what we have termed background traffic (see below).

The APM operates using the following design model. The APM exploits a phase of “perception” of all the communication channels; in this phase it “sniffs” and captures all frames related to those channels and builds an empirical evaluation of the actual traffic it perceives. The
APM policy then builds a sorted list of best APs using the traffic evaluation and the corresponding achievable hypothetical bandwidth.

Our empirical evaluation is based on the following assumptions: the 802.11 physical layer uses the DS-SS (Direct Sequence Spread Spectrum) with the time slot \( T_{\text{slot}} \) that is equal to 20µs; the 802.11 MAC layer uses the Distributed Coordination Function (DCF) with a Minimum Contention Window (CW) size that is \(CW_{\text{min}}=15\). Based on these configurations, the resulting Distributed InterFrame Space (DIFS) is 68µs. Finally, we assume that the random backoff time we have termed \( T_{\text{backoff}} \) is, on average, the \( T_{\text{slot}} \) multiplied by the half of the \(CW_{\text{min}}\), i.e., \( T_{\text{backoff}} \) is equal to 150µs approximately.

In our design approach, every time the MS needs to select an AP, the APM starts a monitoring phase where it checks each channel and receives packets for a fixed monitoring interval (i.e., \( T_{\text{mon}} \)). For each channel, the APM computes the time spent by the channel to transmit packets over the \( T_{\text{mon}} \) as follows:

\[
T_{\text{pkt}}^{Ch} = \sum_{\forall \text{pkt} \in Ch} \left( \frac{\text{size}_{\text{preamble}}}{\text{rate}_{\text{preamble}}} + \frac{\text{size}_{\text{pkt}}}{\text{rate}_{\text{pkt}}} + \text{DIFS} + T_{\text{backoff}} \right)
\]

Equation (1) computes the traffic generated on a channel (the channel is identified by the number \( Ch \)) by measuring the time used to transmit each packet the APM receives on the channel \( Ch \). This time is obtained by summing the time to send a packet preamble, the time to send the data packet itself (note that we have different rates for sending packets and their preambles), the DIFS, and the above estimated \( T_{\text{backoff}} \).

The approach described so far does not take into account the interferences on the channel, which may notably influence the performance exhibited by the APs. Interferences lead to packets loss; hence packets are to be retransmitted on the channel. When the packet is retransmitted, the MAC layer sets the bit “retry” in the MAC header. Thus, we compute the time spent for the retransmission of packets with the “retry” bit set using (2). It is likely that, in the retransmission phase, the rate does not change and we can approximately compute the time for sending a lost packet as in case of (1):

\[
T_{\text{pktlost}}^{Ch} = \sum_{\forall \text{pktlost} \in Ch} \left( \frac{\text{size}_{\text{preamble}}}{\text{rate}_{\text{preamble}}} + \frac{\text{size}_{\text{pktlost}}}{\text{rate}_{\text{pktlost}}} + \text{DIFS} + T_{\text{backoff}} \right)
\]

Hence, the total transmission time of the channel \( Ch \) can be calculated using (3):

\[
T_{Ch} = (T_{\text{pkt}}^{Ch} + T_{\text{pktlost}}^{Ch})
\]

The percentage of available time (i.e., \( T_{\text{free}} \)) for the transmission on the channel \( Ch \) over the monitoring interval is equal to:

\[
T_{\text{free}} = 1 - \frac{T_{Ch}}{T_{\text{mon}}}
\]

Using the available time for the transmission, as computed in (4), we calculate the hypothetical bandwidth an AP can provide on the channel \( Ch \).

\[
BW_{\text{hyp}} = T_{\text{free}} \ast \left[ \text{max size}_{\text{pkt}} \ast \left( \frac{\text{size}_{\text{pkt}}}{\text{rate}_{\text{pkt}}} + \text{max size}_{\text{pkt}} + \text{DIFS} + T_{\text{backoff}} \right) \right]
\]

Equation (5) takes into account the rate to send the packet preamble, the maximum size (i.e., 1518B) of the packets allowed by the 802.11 standard, and the hypothetical rate for sending the packets. The hypothetical rate an AP can reach depends on the signal strength. We have evaluated the hypothetical rate of an AP based on the RSSI. Table 1 shows this evaluation. The “dBm” row of Table 1 represents the minimum signal strength for which it is guaranteed the transmission rate shown in the corresponding row “Mbps”. For example, with -77dBm the hypothetical rate cannot be greater than 36 Mbps. With strengths greater than or equal to -71dBm the hypothetical rate is always 54 Mbps.

To conclude, the selected AP is that with the highest hypothetical bandwidth, as computed in (5).

<table>
<thead>
<tr>
<th>Table 1. Hypothetical channel rate</th>
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<tr>
<td>dBm</td>
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<tr>
<td>Mbps</td>
</tr>
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</table>

4. The extended MEW architecture

We have implemented five principal design choices in the extended MEW architecture. The combined use of these choices allows us to achieve the four main results mentioned in the Introduction of this paper; moreover, they contribute to face the resource constraint issues that emerge in resource-intensive wireless contexts such as those in which MEW operates. The five design choices implemented at both MS and CC sides can be summarized as follows.

1) **Short range wireless communication technologies**: the power consumption and electromagnetic radiation emissions can be notably reduced using IEEE802.11 communications, rather than using long range wireless communications (e.g., GPRS, UMTS, WiMax) [2];

2) **Multi homing**: MEW MSs are equipped with multiple wireless network adapters in order to exploit the connections with different APs and augment the availability of the wireless communications;

3) **Dynamic configuration of the wireless adapter**: each wireless network adapter of a given MS must be configured before starting the communication with an AP. This configuration consists of a) selecting the AP with which associate the wireless adapter, b) associating the wireless adapter with the selected AP, and c) configuring the wireless adapter’s network layer by obtaining an IP address and other information (e.g., netmask, gateway, and DNS server). Every time the wireless adapter loses the AP carrier, (for example due to the MS mobility), all the above
configuration steps must be performed again and a new AP has to be selected;

4) SSL over TCP connections between the MS to the CC: every time a given MS wireless adapter has been configured at both datalink and network layers, the MS establishes an SSL(over TCP) connection with the remote CC through this adapter. This provides bidirectional protected and secure data transmissions;

5) Session-layer multiple path network Load Balancing: the multimedia data produced by a MS are transmitted to the remote CC through all the available SSL connections with the CC (i.e., through all the available MS wireless network adapters). This allows MEW to use the overall bandwidth provided by the different APs with which the adapters are associated. In case of unavailability of the communication through a given MS adapter, the audio/video frames lost will be retransmitted through a different available adapter. In particular, this design choice contributes to provide the MS with sufficient bandwidth and full communication reliability.

Figure 2. Mobile Sensor software architecture

The architecture that implements our five design choices within the MS device is depicted in Figure 2. As shown in Figure 2, the MS architecture includes a micro-camera and a microphone. The microphone samples a single audio channel (mono) at a 44.1 KHz frequency (CD quality). The micro-camera captures grey scale images of 352x288 pixels with a sample frequency of 25 frames/sec. The audio/video data captured by the microphone/micro-camera are passed to the MS Encoder component, as shown in Figure 2. The Encoder encodes audio/video frames, inserts them in an mp4 container, and delivers them to the LoadBalancer for the transmission to the CC. The video codec is the free open-source lossy codec x.264, which has been configured to work in 1-pass mode so as to produce the output as soon as the video frames are delivered from the micro-camera. The audio codec is the HE-AAC, defined in MPEG-4. The MS receives from the micro-camera 2474 KB at each second. The video codec encodes the video stream with negligible delays and produces an encoded video stream of 165 Kbps with reasonable low quality loss. The microphone generates a 344 Kbps audio stream that is encoded producing 32 Kbps of encoded audio.

In essence, the MS produces 195 Kbps of encoded audio and video that the MS LoadBalancer component sends to the CC through all the available SSL connections (each SSL connection is bound to a different MS adapter). The LoadBalancer is responsible for monitoring the performance (i.e., throughput and overall latency) of the SSL connections, fragmenting the encoded audio/video stream, and sending the fragments through the SSL connections to the CC. The higher the performance of a given connection, the larger the portion of fragments sent through that connection. When a MS adapter becomes unavailable, as it loses the AP carrier for example, its SSL(over TCP) connection is tired down and possibly lost data are retransmitted via the remaining working adapters. The unavailable adapter is reconfigured so as to use an alternative AP, and a novel SSL(over TCP) connection with the CC is established through this adapter. At the CC receiving end, the session-layer software receives the fragments and reassembles them in order to reconstruct and store the input data stream.

4.1. Dynamic configuration of wireless adapters

The monitoring and configuration of both datalink and network layers of the MS adapters are managed by the Monitor component that coordinates with the APM, wpa_supplicant, and DHCP client components of the MS architecture, as shown in Figure 2. The Monitor also communicates with the Linux kernel through a datagram-oriented Netlink socket: when a network adapter changes its status, the kernel informs the Monitor, which in turn activates the adapter reconfiguration procedure introduced above. Moreover, the Monitor communicates with the session-layer LoadBalancer to inform it that a wireless network adapter has been configured and can be used.

When a MS adapter is to be configured, the Monitor creates an instance of the APM. The APM works at the datalink layer and it is implemented using the Linux Wireless Extensions API. The APM guides the adapter in scanning the wireless channels, creating a sorted list of the possible candidate APs for that adapter. The list is passed to the Monitor component that excludes from it the APs already associated with a different wireless adapter of the same MS, and the APs for which there are no information required for the authentication process. The wpa_supplicant is then responsible for carrying out the association and authentication procedures with the first available AP in the list. Finally, the DHCP client configures the adapter’s network layer.

5. Experimental Evaluation

The extended MEW architecture prototype, implemented in a Linux-based system and described in the previous
Section, has been used to carry out a two-phase experimental evaluation. The first phase aims at assessing the APM ability to select the best AP among a set of candidate ones. The candidate APs (i) are affected by different traffic configurations, (ii) exhibit different signal strengths, and (iii) use radio channels that might be overlapped. The second phase aims at assessing the behavior of the extended MEW architecture.

The objective of the first phase is twofold; namely, it is used to assess both the APM ability to adequately model the traffic and AP signal strength, and recognize the AP that provides the highest bandwidth. A MS’s APM monitors three available APs that operate at a nominal rate of 54 Mbps in different non-overlapping channels (i.e., channels 1, 7, 13). Table 2 summarizes the obtained results.

<table>
<thead>
<tr>
<th>Table 2. Selection among non overlapping APs</th>
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<tbody>
<tr>
<td>AP1, Medium Signal Strength, Low Traffic</td>
</tr>
<tr>
<td>1 Traffic (Bw)</td>
</tr>
<tr>
<td>2 Avg. Strength</td>
</tr>
<tr>
<td>3 % Tpkt</td>
</tr>
<tr>
<td>4 % Tpktlost</td>
</tr>
<tr>
<td>5 % Tocc</td>
</tr>
<tr>
<td>6 % Ttree</td>
</tr>
<tr>
<td>7 Hypot. Rate</td>
</tr>
<tr>
<td>8 AP Quality (Hypot. Bw)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>9 200Kbps RTT</td>
</tr>
<tr>
<td>10 2Mbps RTT</td>
</tr>
</tbody>
</table>

Each column of Table 2 relates to a different AP whereas each row describes the different estimated parameters of our APM design model. Specifically, row 1 represents the background traffic we have injected for each AP, row 2 represents the average signal strength of each AP as perceived by the MS, and row 3 is the percentage of time, over the monitoring interval, used to transmit the MS received packets as computed in (1). Analogously, row 4 represents the percentage of time used for transmitting the lost packets and row 6 shows the available time percentage on the channel of each AP, calculated according to (4). Row 7 contains the hypothetical AP rate and finally row 8 represents the AP hypothetical bandwidth as calculated in (5) (i.e., the AP quality indicator).

The AP scenario has consisted of (i) AP1 affected by a low traffic level (2 Mbps) but providing medium signal strength (-77 dBm), (ii) AP2 affected by a high traffic level (20 Mbps) and providing medium signal strength (-77 dBm), and finally (iii) AP3 providing very high signal strength (-50 dBm) but affected by high traffic level. We ran the APM in a MS for 13 seconds, so that each of the 13 channels is monitored for 1 second (i.e., $T_{mon} = 1$). From the first set of experiments we can conclude that if we had used the common AP selection policy, the highest signal strength AP3 would have been selected as the best AP among those available. In contrast, our APM assesses that the best AP is AP1, despite it provides medium signal strength.

After the monitoring phase, to confirm the effectiveness of the selected AP, the MS associated with each AP of our scenario and sent to each AP the amount of multimedia data it produced, i.e., 200 Kbps data composed by 25 frames of approximately 1000B; moreover, it waited for an acknowledgment of the same size. Row 9 shows the obtained RTTs in this case. Analogously, the MS sent 25 frames of 1000B, and waited for the acknowledgment; in this case, the RTTs are shown in row 10. As it can be seen, the selected AP1 provides the MS with the best performance; rather, the highest signal strength AP3 appears slightly overloaded.

The second evaluation phase aims at assessing the behavior of the extended MEW architecture. The scenario in this case can be described as follows. An operator wears a MEW MS that is equipped with two IEEE802.11g wireless adapters (W1 and W2); the operator walks along a 200m urban path (i.e., in our city Bologna), sending to the CC the multimedia frames it captures. The CC collects the Storage Delay of each received video frames (i.e., the time elapsed between the capturing of a video frame by the micro-camera and the delivery of that frame to the decoder at the CC). At the beginning of the path, four APs are available: two of them (i.e., AP1 and AP2) provide medium signal strength (greater than -76 dBm) and carry very low traffic (lower than 1 Mbps); the other two remaining APs (i.e., AP3 and AP4) provide high signal strength (greater than -55 dBm) and are affected by a high traffic level (20 Mbps).

As in the scenario of Table 2, the APM selects the two low traffic level APs (AP1 and AP2) and the Monitor configures the two MS wireless adapters such that W1 is associated with AP1 and W2 with AP2, in order to transmit the frames to the CC. After approximately 70m a further medium signal level AP with low traffic level (i.e., AP5) becomes available. After approximately 100m, a building obscures the AP2 signal, so that the W2 adapter becomes unavailable and some IP datagram are lost. The LoadBalancer retransmits the audio/video frames that are lost using the survival W1 adapter that is associated with AP1. Meanwhile, the APM (following the Monitor instructions) searches for another best AP and it delivers the Monitor the list of available detected APs. The best AP is the AP5; thus, the W2 adapter is associated with AP5 and its network layer configured. The LoadBalancer establishes a new SSL connection with the CC and starts sending multimedia frames using both the wireless adapters W1 and W2.
The extended MEW system provides the multimedia MSs with sufficient bandwidth, responsiveness, and reliability despite the handoff and the typical scarce wireless resource problems emerging in the metropolitan wireless context we have used in our evaluation.

6. Related Work

A large body of research has investigated AP selection mechanisms and produced a number of research works that, for the sake of brevity, we briefly summarize in this Section. We have identified two principal research work categories; namely the category of those works that operate at datalink layer and the category of researches that works at the higher levels of the ISO/OSI stack.

In the works that fall into the first category, different parameters are considered in isolation for the selection of the best AP. For instance, [6] uses the potential bandwidth (not the available bandwidth) exhibited by the APs; [4] uses the QoS parameters APs should provide mobile devices with by following the 802.11h specifications; further works use the link quality or the number of mobile devices [3] associated with a given AP. Although our APM component operates at the same layer as that proposed in these works, we empirically estimate the hypothetical available bandwidth of the APs, and we select the best AP based on this metric and the influence of all the above parameters on this metric. In addition, our APM is used in the extended mobile system MEW, which operates in a different scenario compared to that of these researches. Specifically, the extended MEW is able to deal with the real heterogeneity of APs that are installed in existing metropolitan areas. In contrast, Virgil [5] falls into the second category above; it operates at a higher level of the ISO/OSI stack and estimates also the quality of each AP’s connection to the Internet. To conclude, the NEMO mobility system [8] may be used in the scenario we have considered in order to achieve our same objectives; however, it requires the use of mobile IPv6. Since MEW uses already existing network infrastructures, which can be administered by different organizations, it cannot rely on the mobility mechanism provided by mobile IPv6.

7. Concluding remarks

This paper has described the design, implementation, and experimental evaluation of an extended version of the MEW surveillance system. Specifically, we have incorporated in this version a component termed Access Point Monitor (APM). The APM is responsible for dynamically selecting the best AP reachable in those metropolitan areas in which MEW operates. To this end, the APM selection policy uses both the signal strength and the traffic and packet losses on the wireless communication channels. Our experimental evaluation shows that such a hybrid selection approach can effectively be used to provide MEW MSs with sufficient bandwidth, responsiveness, and reliability in the transmission of multimedia data streams. Our future works include extending the APM design model to estimate the effects of channel overlapping.

8. References