Intelligent Multimedia Coding over Oblivious Networking Protocols
A Case for a Cross Layer Multimedia Architecture

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School of Electrical Engineering & Computer Science
National University of Sciences & Technology (NUST), Pakistan
Talk Outline

About the Speaker

Wireless Multimedia: Applications and Impact

Challenges of Wireless Multimedia

A Case for a Cross-Layer Wireless Multimedia Architecture
About NUST

- NUST was established as an Engineering University in 1991
- Since then, it has expanded its scope to include Medical and Management Sciences as well
- The University was originally based on the concept of multiple campuses in different cities
- Now all the campuses are being consolidated into a single campus in Islamabad
About NUST: Distributed NUST Campuses
About NUST: New Campus

- Sport Complex
- Academic Block
- Students Hostel
- Faculty & Staff Residency
- 700 Bed (Teaching hospital)
NUST Declared as

- No. 1 in PAKISTAN

- No. 20 in ASIA

(Source: Asia Week, Issue June 30th 2000)
About NUST-SEECS: University Collaborations

- Canada
- USA
- France (UBO)
  - Germany
  - Switzerland
  - Sweden
  - UK
  - Denmark
- China
- Korea
- Japan
- Thailand
- Singapore
- Australia
About NUST-SEECS: Selected Collaborations

- **UBO** has recently accepted a NUST student under the Sandwich program
  - A funding application is also being submitted to the ICT-Asia-France Programme
- **Cisco Systems** has recently established a “Center for Excellence in IP Technologies” at SEECS
- **IBM** established a “Center for Open-Source Technologies” at SEECS in 2007
- **CERN (Geneva)** since December 2001 and awarded “Associate Membership” of CERN
- **Caltech University, USA** on project titled “Interactive Grid Analysis Environment (IGAE)”
- **Stanford University, USA** is working on two active projects with NUST-SEECS
- **Nokia Research** China has given a research grant to SEECS to investigate “Design of Adaptive Multimedia Protocols”
- **Other Funded Projects:** ICT-Asia-France, Korean Research Foundation, Pakistan National ICT R&D Fund
About the speaker

- PhD (Electrical Engineering): Michigan State University (MSU), December 2006
- Assistant Professor: School of Electrical Engineering & Computer Science (SEECS), National University of Sciences & Technology (NUST), Pakistan
- Founding Director: Wireless and Secure Networks (WiSNet) Research Lab
- CEO and Co-Founder: Baltoros Limited

Wireless and Secure Networks Research Lab
http://wisnet.seeecs.edu.pk

BALTOROS
Unleash the dark side of your network!
http://www.baltoros.com
About WiSNet: Focal Research Areas

- Wireless Communication
- Network and Information Security
- Bio-inspired Computing
- High Performance Computing
About WiSNet: Funded Projects

National ICT R&D Fund

Nokia Research Center

KSAA
About WiSNet: Selected Journal Publications
**About WiSNet Lab: USPTO Pending Patents**

**PATENTS FILED IN USPTO**

**PATENT 1**
**[HEADER ESTIMATION TO IMPROVE MULTIMEDIA QUALITY OVER WIRELESS NETWORKS]**

**FILING DATE:** 01.02.2008

**APPLICANTS:** BOARD OF TRUSTEES OF MICHIGAN STATE UNIVERSITY [US/US]
RADHA, HAYDER [US/US]
KHAYAM, SYED, ALI [PK/US]

**INVENTORS:** RADHA, HAYDER [US/US]
KHAYAM, SYED, ALI [PK/US]
KARANDE, SHIRSH S. [IN/US]

**PRIORITY DATA:** 01.02.2008

**TITLE:** HEADER ESTIMATION TO IMPROVE MULTIMEDIA QUALITY OVER WIRELESS NETWORKS

**ABSTRACT:** A METHOD IS PROVIDED FOR ESTIMATING THE HEADER OF A DATA PACKET IN A WIRELESS COMMUNICATION SYSTEM. THE METHOD INCLUDES: MAINTAINING A LIST OF DATA PACKETS RECEIVED WITHOUT AN ERROR AT A RECEIVER; RECEIVING AT THE RECEIVER A CORRUPT DATA PACKET HAVING ERRORS IN ITS HEADER; COMPUTING A LIKELIHOOD SCORE FOR THE HEADER OF THE CORRUPT DATA PACKET IN RELATION TO EACH ENTRY IN THE LIST OF DATA PACKETS; AND SELECTING AN ENTRY HAVING THE HIGHEST LIKELIHOOD SCORE AS AN ESTIMATED HEADER FOR THE CORRUPT DATA PACKET.

**FIGURE:**

**PATENT 2**
**[ON CHANNEL STATE INFERENCE AND PREDICTION USING OBSERVABLE VARIABLES IN 802.11B NETWORK]**

**FILING DATE:** 01.11.2008

**APPLICANTS:** BOARD OF TRUSTEES OF MICHIGAN STATE UNIVERSITY [US/US]
ELECTRONICS AND TELECOMMUNICATION RESEARCH INSTITUTE (ETRI), DAEJON, SOUTH KOREA

**INVENTORS:** KARANDE, SHIRSH S. [IN/US]
KHAYAM, SYED ALI [PK/US]
CHO, YONGJU [KR/KR]
RADHA, HAYDER [US/US]
KIM, JAEKON [KR/KR]
HONG, JIN-WOO [KR/KR]

**PRIORITY DATA:** 01.11.2008

**TITLE:** ON CHANNEL STATE INFERENCE AND PREDICTION USING OBSERVABLE VARIABLES IN 802.11B NETWORK

**ABSTRACT:** THE PRESENT INVENTION PROPOSES A METHOD AND APPARATUS TO UTILIZE OBSERVABLE CHANNEL SIDE INFORMATION PROVIDED BY WIRELESS DEVICES TO FACILITATE HIGHER LAYER PROTOCOLS AND APPLICATIONS.

**FIGURE:**

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**PATENTS FILED IN IPO PAKISTAN**

**PATENT 1**

**APPLICATION NO.:** 810/2008  
**FILING DATE:** 09-07-2008

**APPLICANTS:** NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY  
SCHOOL OF ELECTRICAL ENGINEERING AND COMPUTER SCIENCE (NUST-SEECS)  
FOUNDATION FOR ADVANCEMENT OF SCIENCES AND TECHNOLOGY (PAST/NU)  
PAKISTAN NATIONAL ICT R&D FUND

**INVENTORS:** M. ZUBAIR SHAQIQ  
DR. MUHAMMAD FAROOQ  
DR. SYED ALI KHAYAM

**PRIORITY DATA:** 09-07-2008

**TITLE:** A METHOD FOR EMBEDDED MALWARE DETECTION

**ABSTRACT:** A method for detection of embedded malware is formulated by analyzing the correlation observed in a benign file’s data. This correlation structure is statistically modeled using Markov chains. For detection of embedded malware, the model is quantified using an information theoretic measure and a classification threshold is determined. Unknown files are then classified using the classification threshold.

**FIGURE:**

![Diagram of Malware Detection](image)

**PATENT 2**

**APPLICATION NO.:** 839/2008  
**FILING DATE:** 15-07-2008

**APPLICANTS:** NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY  
SCHOOL OF ELECTRICAL ENGINEERING AND COMPUTER SCIENCE (NUST-SEECS)  
FOUNDATION FOR ADVANCEMENT OF SCIENCES AND TECHNOLOGY (PAST/NU)  
PAKISTAN NATIONAL ICT R&D FUND

**INVENTORS:** M. ZUBAIR SHAQIQ  
DR. MUHAMMAD FAROOQ  
DR. SYED ALI KHAYAM

**PRIORITY DATA:** 15-07-2008

**TITLE:** DETECTION OF TRAFFIC ANOMALIES IN A COMPUTER NETWORK

**ABSTRACT:** The present invention presents a set of intelligent statistical features which can improve the classification accuracy of a bio-inspired classifier operating on these intelligent features. The feature set acts as an input to the bio-inspired classifier.

**FIGURE:**

![Diagram of Traffic Anomaly Detection](image)
WIRELESS MULTIMEDIA: APPLICATIONS AND IMPACT
Wireless multimedia is becoming increasingly pervasive

An overwhelming success of wireless voice networks has catalyzed built-in support for video communication in new wireless communication standards.
Wireless offers a direct application in broadcasting technology

AT&T Mobile TV

get TV to go
Tune-in 24/7 for full-length, broadcast quality episodes of your favorite TV shows on the networks you love. Get Mobile TV from AT&T, and turn any time into prime time.

Learn more about Mobile TV ➔
Wireless multiplayer gaming is also around the corner
Wireless technology offers a cheap, fast communication option for unprivileged regions
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Wireless technology offers a cheap, fast communication option for unprivileged regions.
Wireless multimedia is a cornerstone for distance learning in unprivileged regions

Learning 2.0 Project of Pakistan
Wireless video telehealthcare options are also being explored now

Telehealth for mountainous areas of northern Pakistan using Satellites

Source: IDRC Report, 2005
Wireless video conferencing is enabling effective R&D collaborations

Sources: www.ivci.com, pixavi.com.
Wireless video is offering interesting new surveillance options

Sources: www.cisco.com.
Wireless video is also being used for habitat and wildlife monitoring.

The Deernet Project

Coastal Monitoring using Aquatic video sensors

Sources: www.cisco.com.
Wireless video is also anticipated to play a vital role in monitoring of disaster struck regions

Autonomous Robots for Observation of Urban Networks after a Disaster (AROUND) Project
CHALLENGES OF WIRELESS MULTIMEDIA
## Conflicting Constraints of “Wireless” and “Multimedia” Technologies

<table>
<thead>
<tr>
<th></th>
<th>Wireless</th>
<th>Multimedia</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bandwidth</strong></td>
<td>Constrained</td>
<td>Requires high bandwidth</td>
</tr>
</tbody>
</table>
Quality of a multimedia application over any network is determined by two parameters:

- **Delay**: High delays cannot be tolerated
- **Bandwidth**: Multimedia data generally requires much more bandwidth than normal traffic

Multimedia transport over wireless channels is different from wired channels mainly because of the following factors:

<table>
<thead>
<tr>
<th></th>
<th>Wireless</th>
<th>Wired</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main packet-loss source</td>
<td>Bit-errors</td>
<td>Congestion</td>
</tr>
<tr>
<td>Data rates</td>
<td>Low (max commercial data rate of 54 Mbps)</td>
<td>High (up to 1 Gbps)</td>
</tr>
</tbody>
</table>
### Intelligent Multimedia Coding over Oblivious Networking Protocols

- Multimedia content can tolerate a certain level of errors in the multimedia content.

- In view of the errors incurred on wireless channels, emerging multimedia standards also provide intelligent error resilience and concealment options:
  - Slices in H.264
  - Reversible Variable Length Coding in MPEG-4

- Despite these intelligent video coding options and the differences between wired and wireless channels, **wireless networking protocols drop all packets with errors at the receiver without regard to the number and location of errors**.
Wireless networking protocols drop all packets with errors without regard to the number and location of errors.

These packets are generally recovered using retransmissions.

On error-prone wireless channels, such a strategy incurs considerable overhead in terms of delay and bandwidth wastage.
A CASE FOR A CROSS-LAYER WIRELESS MULTIMEDIA ARCHITECTURE

LET ME EXPLAIN WHAT VIDEO COMPRESSION IS...

WOULD YOU STOP IF I POINTED OUT THAT EVERYONE IN THIS ROOM EXCEPT YOU IS AN ELECTRICAL ENGINEER?

ZEROS ARE ROUND AND FAT COMPARED TO ONES...
I'M BEGGING YOU...
A Case for a Cross-Layer Multimedia Architecture

- Wireless networking protocols drop all packets with errors without regard to the number and location of errors.

- On error-prone wireless channels, such a strategy incurs considerable overhead in terms of delay and bandwidth wastage.

- It is widely agreed that wireless multimedia transport protocols should relay corrupted packets to the application layer because:
  - Most of the data in corrupted packets is error-free.
  - Corrupted data can be recovered using an application layer FEC with incurs lesser bandwidth wastage than retransmissions.
  - FEC-based recovery has much lower delay than retransmissions.
  - Errors not corrected by FEC can be handled by error-resilient multimedia applications.
Multimedia Transport over Wireless Channels:

- It is widely agreed that wireless multimedia transport protocols should relay corrupted packets to the application layer.

- To achieve this objective, we must borrow information from different layers of a wireless protocol stack, something known as cross-layer communication in networking literature.

- This is generally not allowed in networking protocols whose fundamental design objective are:
  - Simplicity
  - Modularity

- So different layers of the protocol stack are not allowed to talk to each other.
Multimedia Transport over Wireless Channels: Layered Architecture

- Multimedia Application
- Transport Layer
- Network Layer
- MAC Layer
- Physical Layer
Multimedia Transport over Wireless Channels: A Receiver-based Cross-Layer Architecture

- Multimedia Application
- Transport Layer
- Network Layer
- MAC Layer
- Physical Layer

Cross-Layer Module
Multimedia Transport over Wireless Channels: UDP

- Until recently, there were two contending protocols for wireless multimedia transport:
  - User Datagram Protocol (UDP)
  - UDP-Lite
**Multimedia Transport over Wireless Channels: UDP**

UDP drops all packets whether the errors hit the header or the payload.

**Case 1:**
No Error

**Case 2:**
Payload errors only

**Case 3:**
Header errors only

**Case 4:**
Both header & payload errors
UDP drops all packets whether the errors hit the header or the payload.
UDP-Lite disables the MAC checksum

At the transport layer, only packet with header errors are dropped
That is, packet payload errors are ignored below the application layer

Case 1: No Error

Case 2: Payload errors only

Case 3: Header errors only

Case 4: Both header & payload errors
UDP-Lite disables the MAC checksum
At the transport layer, only packet with header errors are dropped.
That is, packet payload errors are ignored below the application layer.

<table>
<thead>
<tr>
<th>Case</th>
<th>Packet header</th>
<th>Packet payload</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: No Error</td>
<td><img src="Case1" alt="Packet header" /></td>
<td><img src="Case1" alt="Packet payload" /></td>
</tr>
<tr>
<td>2: Payload errors only</td>
<td><img src="Case2" alt="Packet header" /></td>
<td><img src="Case2" alt="Packet payload" /></td>
</tr>
<tr>
<td>3: Header errors only</td>
<td><img src="Case3" alt="Packet header" /></td>
<td><img src="Case3" alt="Packet payload" /></td>
</tr>
<tr>
<td>4: Both header &amp; payload errors</td>
<td><img src="Case4" alt="Packet header" /></td>
<td><img src="Case4" alt="Packet payload" /></td>
</tr>
</tbody>
</table>
While UDP-Lite significantly reduces the number of packet drops at a wireless receiver, it has two main shortcomings:

- Bursty wireless errors cause considerable header errors, thus resulting in considerable packet drops (up to 40% at an 11 Mbps 802.11b LAN)
- UDP-Lite requires changes to the transmitter and multicast/multihop nodes

We wanted to devise a receiver-based wireless transport framework that minimizes packet drops at a wireless receiver.
We wanted to devise a receiver-based wireless transport framework that minimizes packet drops at a wireless receiver.

The framework that we developed, called Header Estimation†,‡, operates on the following simple principle:

– If a received packet is corrupted, try to estimate the correct (transmitted) value of the (possibly corrupted) critical header fields (CHF) in the packet
– If estimation confidence is high, pass the packet to the application layer

No packet drops
Packet with corrupted headers are estimated and passed to the application layer

Case 1: No Error
Case 2: Payload errors only
Case 3: Header errors only
Case 4: Both header & payload errors
Header Estimation: A Cross-Layer Multimedia Framework

- **Application Layer**
  - Pkt after network and transport layer processing

- **Network and Transport Layers**
  - Error-free pkt
  - MAC Layer without UDP
  - Pkt Drops
  - Received pkt after physical layer processing

- **Network and Transport Layers with Disabled Checksums**
  - Corrupt UDP pkt which has either dst MAC or dst IP address of local

- **Header Estimation**
  - Corrupt UDP pkt with *estimated* CHF

**List of active CHF**
We have theoretically and experimentally compared the performance of header estimation with UDP and UDP-Lite:

- **Theoretical comparison:** We derive and compare lower bounds on the amount of FEC redundancy required by ideal header estimation, UDP-Lite and UDP

- **Experimental comparison:** For varying coding rates, we compare the multimedia quality of a practical header estimation scheme with UDP-Lite and UDP
Analytical Evaluation

- We have derived lower bounds on the minimum expected FEC redundancy required by the three protocols:
  - UDP: Drop all corrupted packets
  - UDP-Lite: Drop corrupted packets with header errors
  - Ideal Header Estimation: Do not drop any packet

- The required FEC redundancy is a function of:
  - FEC code rate and error correction capability
  - The underlying wireless channel model at the receiver’s MAC layer
Analytical Evaluation: FEC

- At application layer, we assume a Maximum Distance Separable (MDS) FEC code with $k$ message symbols and $r$ redundant symbols.

- For UDP-Lite and header estimation, we assume that the code is capable of joint error-erasure recovery.
  - An MDS joint error-erasure FEC code can correct $X$ errors and $Y$ erasures in a codeword if:

  $$r \geq 2X + Y$$

- We want to derive a lower bound on $r$ in terms of wireless channel parameters.
Eight bit symbols
All packet drops are considered to be erasures
We assume that the MAC layer bit-error channel is an arbitrary-order Markov wireless channel.

In a K-th order Markov channel, any given bit is dependent on K previous bits.

Transition probabilities of the channel model are computed by sliding a K-bit window over the training data and counting the number of times a K-bit vector $x$ is followed by another vector $y$.

Thus the total number of states are $2^K$.

That is, a state corresponding to each unique K-bit combination.
Analytical Evaluation: Channel Model

A 3-rd order Markov channel model†

Analytical Evaluation: FEC Redundancy Bounds

FEC redundancy lower bounds on UDP, UDP-Lite and Ideal Header Estimation are\(^\dagger\):

\[
r_{udp} \geq n_D l \left[ 1 - (p_{0,0})^{n_H + n_D - K} \sum_{i=0}^{2^{K-1}-1} \left( \pi_{2i} \prod_{j=1}^{K} p_{2i,2j(2i)} + \pi_{2i+1} \prod_{j=1}^{K} p_{2i+1,2j(2i+1)} \right) \right]
\]

\[
r_{lite} \geq n_D l \left[ 1 - (p_{0,0})^{n_H - K} \sum_{i=0}^{2^{K-1}-1} \pi_{i,2i(2i)} (1 - 2\pi_{b}^{(bit)}) \left( \prod_{j=1}^{K} p_{2i,2j(2i)} + \pi_{2i+1} \prod_{j=1}^{K} p_{2i+1,2j(2i+1)} \right) \right]
\]

\[
r_{hdr\_est} \geq 2n_D l \pi_{b}^{(bit)}
\]

Comparison of the bounds yields:

\[
\min (r_{udp}) > \min (r_{hdrest}) \text{ if } \pi_b^{(pkt)} > 2\pi_b^{(bit)}
\]

\[
\min (r_{lite}) > \min (r_{hdrest}) \text{ if } \pi_b^{(bit)} < 0.5
\]

The above conditions are true for any realistic channel.

Thus UDP and UDP-Lite always requires more redundancy than Ideal Header Estimation to achieve the same level of error-free recovery.
We now know that an ideal header estimation scheme should perform better than UDP and UDP-Lite.

Then the question is: **How do you achieve accurate header estimation in a low-complexity manner?**

We have identified at least three methods of achieving low-complexity and near-ideal header estimation:

- Bayesian Approach
- **Maximum-Likelihood Approach**
- Minimum Distance Decoding Approach
To achieve practical header estimation, we map the CHF estimation problem to the well-known problem of maximum-likelihood estimation of known parameters in noise.

Then for the received CHF in a corrupted packet, the true value of the CHF are estimated by computing the likelihood score for each multimedia session.

- The session with the highest likelihood score is chosen as the CHF estimate.

Thus a likelihood function for the present channel model has to be derived.
Experimental Evaluation: Maximum-Likelihood Header Estimation

The likelihood function for the present problem is given by:

\[
\Pr \{ \hat{x}_r | x_i, X_n \} = \pi_{u_i} \Pr \{ u_i \rightarrow (2v_i + z_i [K + 1]) \mod 2^K \} ^{W-K-1} \Pr \left\{ \bigg( 2^{s-1} u_i + \sum_{b=0}^{s-2} 2^{s-1-b} z_i [K + 1 + b] \bigg) \mod 2^K \right\}
\]

where:

- \( z_i = \hat{x}_r \oplus x_i \),
- \( \hat{x}_r \): received CHF,
- \( x_i \): CHF of an active multimedia

Experimental Evaluation: Wireless Testbed

- We tested ML header estimation under many different setups of an 802.11b LAN

- H.264 video streams with different source coding rates were transmitted on the wireless channel
Experimental Evaluation: Throughput

(a) 2 Mbps

(b) 5.5 Mbps

(c) 11 Mbps
Experimental Evaluation: FEC Decoding

(a) 2 Mbps

(b) 5.5 Mbps

(c) 11 Mbps
Experimental Evaluation: PSNR

(a) 2 Mbps

(b) 5.5 Mbps

(c) 11 Mbps
Experimental Evaluation: Video Results

UDP Lite

UDP

Header Estimation

data rate = 11 Mbps, redundancy=2 bytes per 30 bytes FEC block
Networking protocols, please please please please stop dropping multimedia packets!
Thank You!

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