A Multi-Processor NoC Platform Applied on the 802.11i TKIP Cryptosystem

January 24, 2008

Jung-Ho Lee

Bit Engineering Lab.

Contents

- Motivation
- Introduction to TKIP
- TKIP overall architecture
- Output Pattern
- Work breakdown and Mapping
- Pipelined Collaboration
- Network Interface
- Conclusion

Motivation

- Since 2001, there have been a myriad of papers on systematic analysis of Multi-Processor System on Chip (MPSoC) and Network on Chip (NoC).

- Nevertheless, we only have a few of their practical application. Till now, main interest of researchers has been to adapt NoC to the communication intensive multimedia system like H.263.

- This paper attempts to expand the domain of NoC platform to one of the wireless security algorithms (TKIP)
  - ✓ because its inter-component transaction pattern shows considerable characteristic for NoC.

TKIP Introduction

- In August, 2001, WEP of 802.11a was cracked by S. Fluhrer, I. Mantin, A. Shamir.
- Less Secure than AES, HMAC-SHA-1 based CCMP algorithm
- TKIP: Temporal Key Integrity Protocol
- New features, when compared to the WEP
  - ✓Message Integrity Code (MIC)
  - ✓IV (Initialization Vector) Sequencing
  - ✓New per-packet key construction
  - ✓Key distribution

Overall TKIP Architecture

TA: Transmit Address

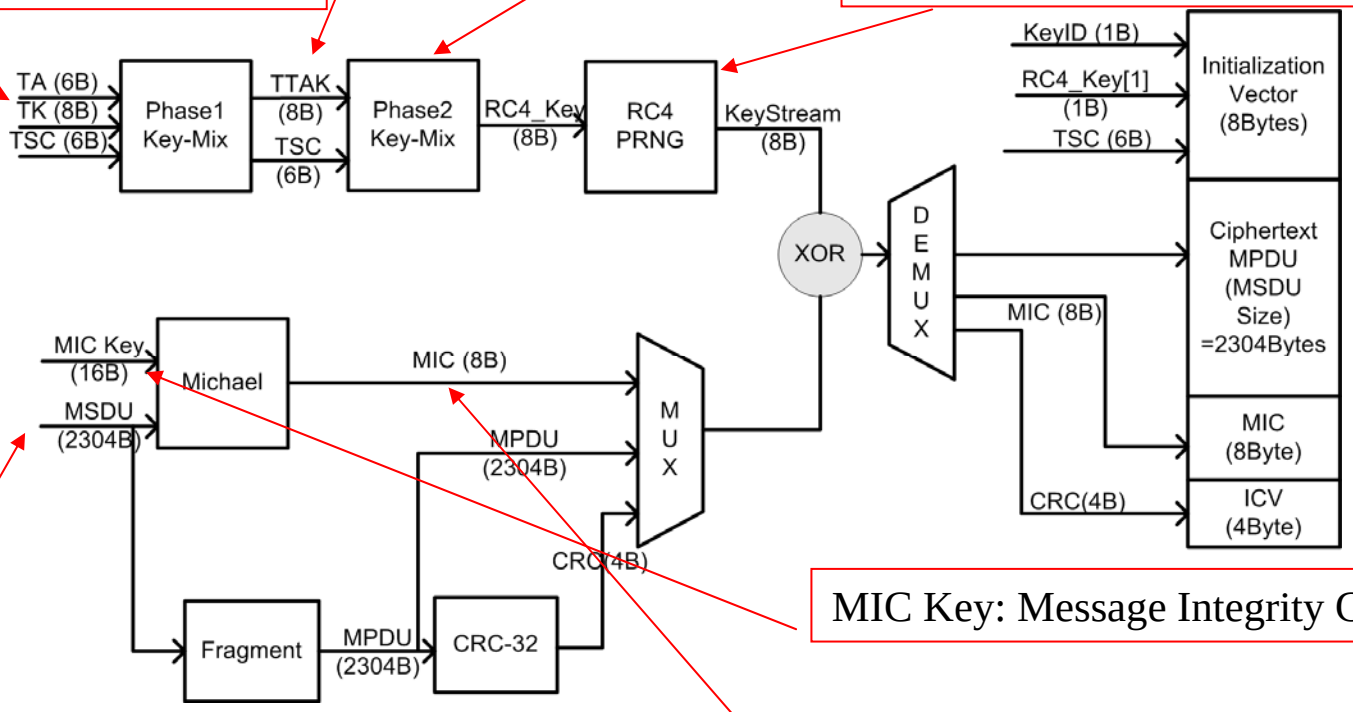
TK: Temporal Key

TSC: TKIP Sequence Counter

TTAK: TKIP-Mixed transmit address and key

KeyMix: De-correlate IV and per-packet key

RC4: A block encryption algorithm



MIC Key: Message Integrity Code Key

MSDU: MAC Service Data Unit

MIC: Message Integrity Code = A Cryptographic checksum

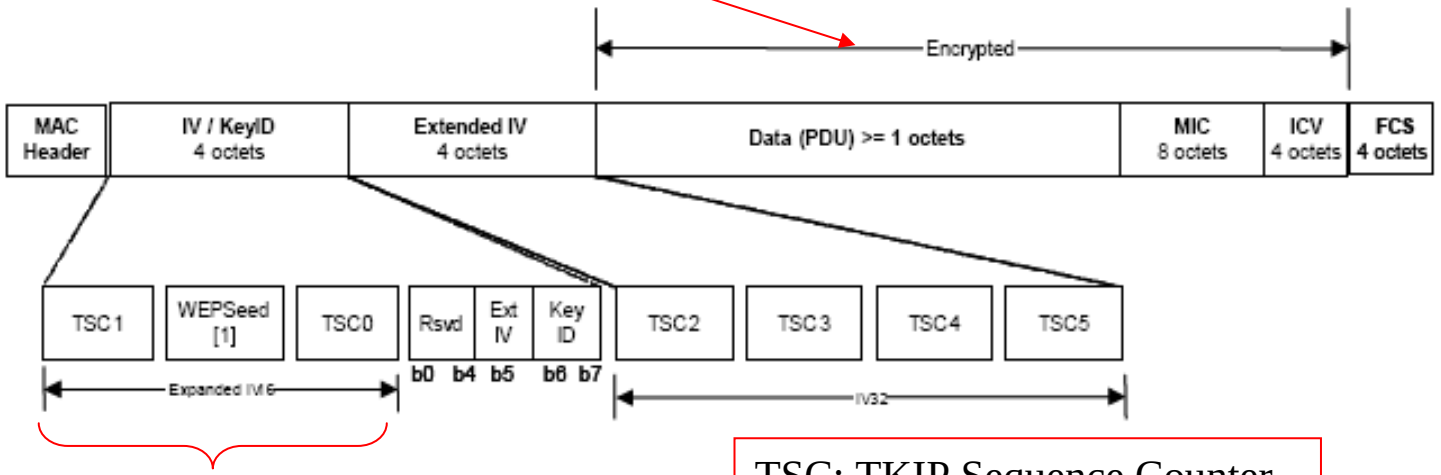
Output Pattern

MPDU, MIC, and ICV are encrypted with RC-4

MIC: Message Integrity Code

using ‘Michael’ algorithm

ICV: Integrity Check Value from CRC-32



Length of IV (Initialization Vector)

is expanded by 16bits (2octets)

TSC: TKIP Sequence Counter

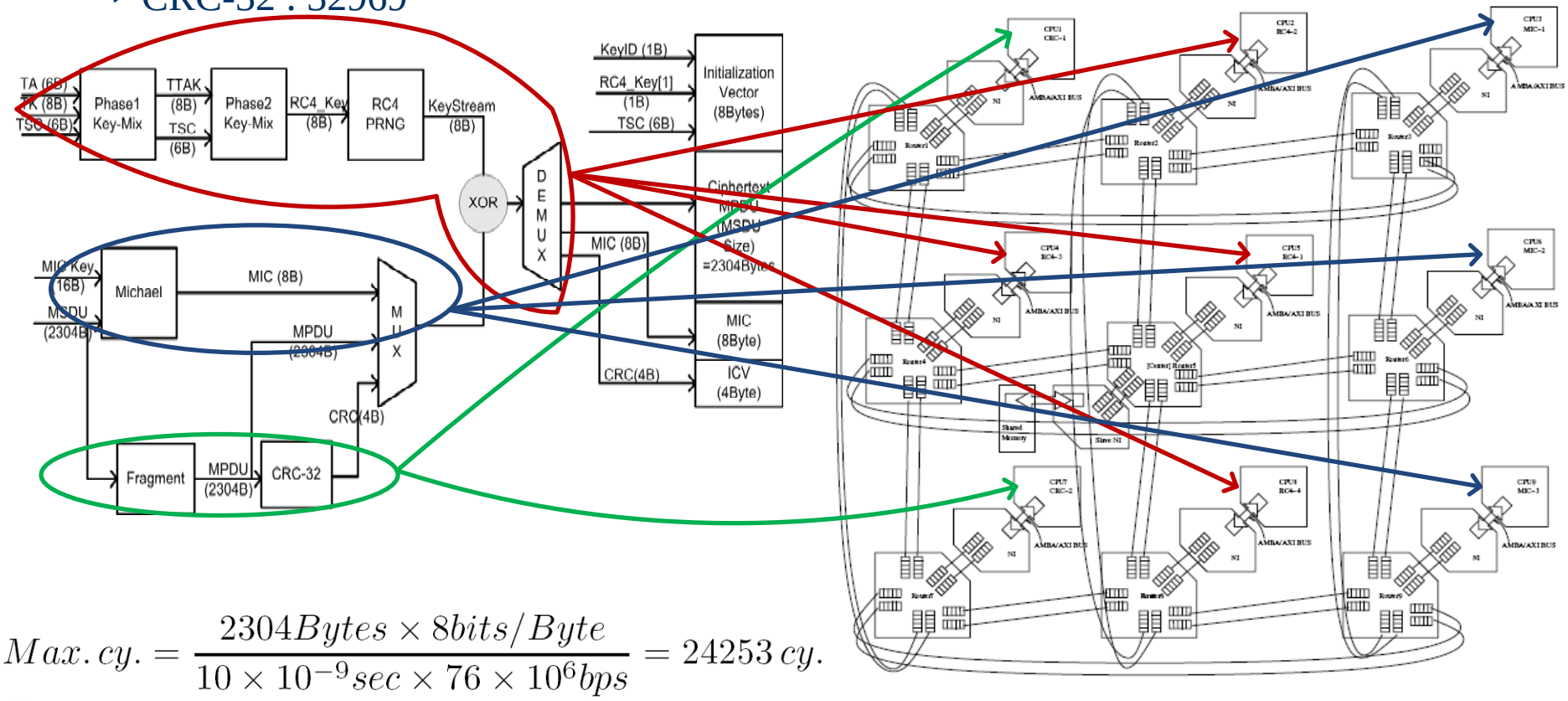
TSC5: Most Significant Octet ~

TSC0: Least Significant Octet

WEP Seed [1]: (TSC1 | 0x20) & 0x7f

Work breakdown and mapping

- Execution cycles for processing a MSDU (2304 Byte) on a single 100 MHz ARM processor ISS (SimItARM)
  - ✓ RC4 + KeyGen : 75693 + 5203 = 80896
  - ✓ Michael : 63040
  - ✓ CRC-32 : 32969



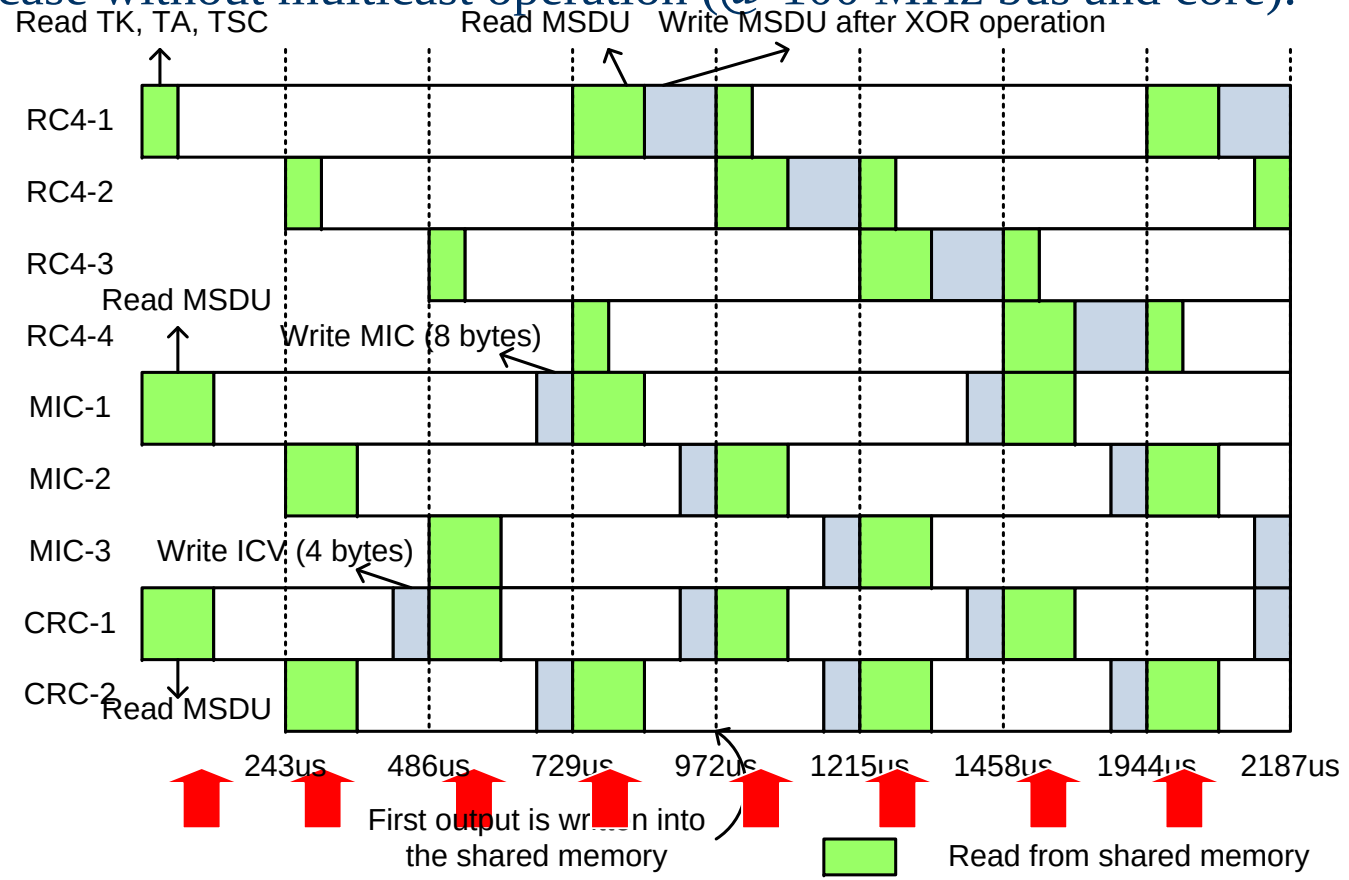
$$Max.cy. = \frac{2304Bytes \times 8bits/Byte}{10 \times 10^{-9}sec \times 76 \times 10^{6}bps} = 24253\,cy.$$

Pipelined Collaboration

- As a result of efficient communication architecture, which is equipped with mul ticast operation, three components can read a MSDU in 10.15us, as opposed to 30.29us in the case without multicast operation (@ 100 MHz bus and core).

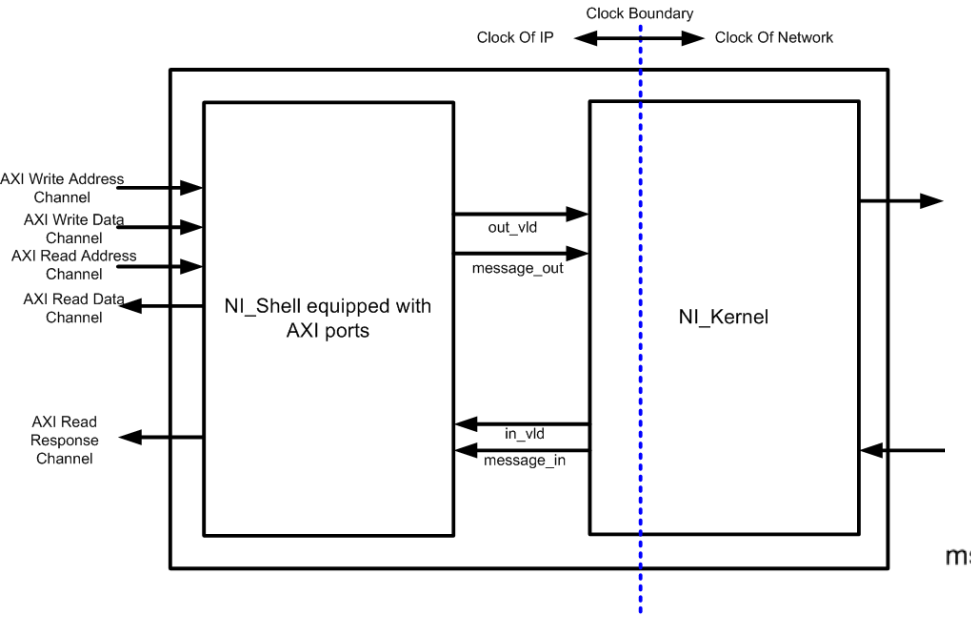
1 Tx Unit = 64 Byte = 16 Burst transfers × 4 Byte/Burst

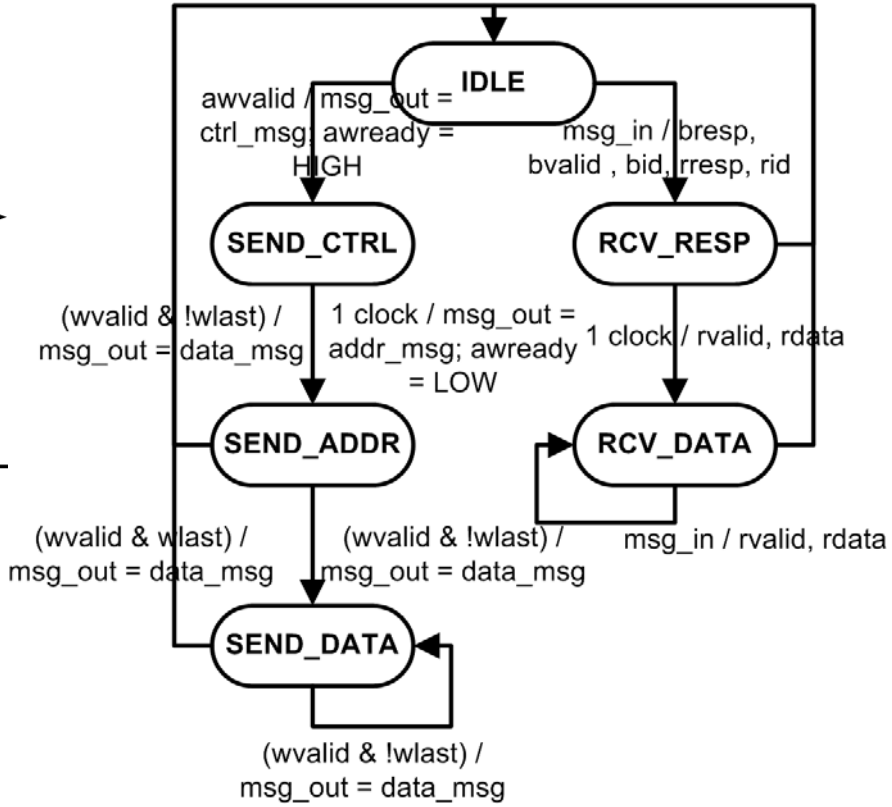
2304 Byte MSDU = 36 Tx Unit



Network Interface

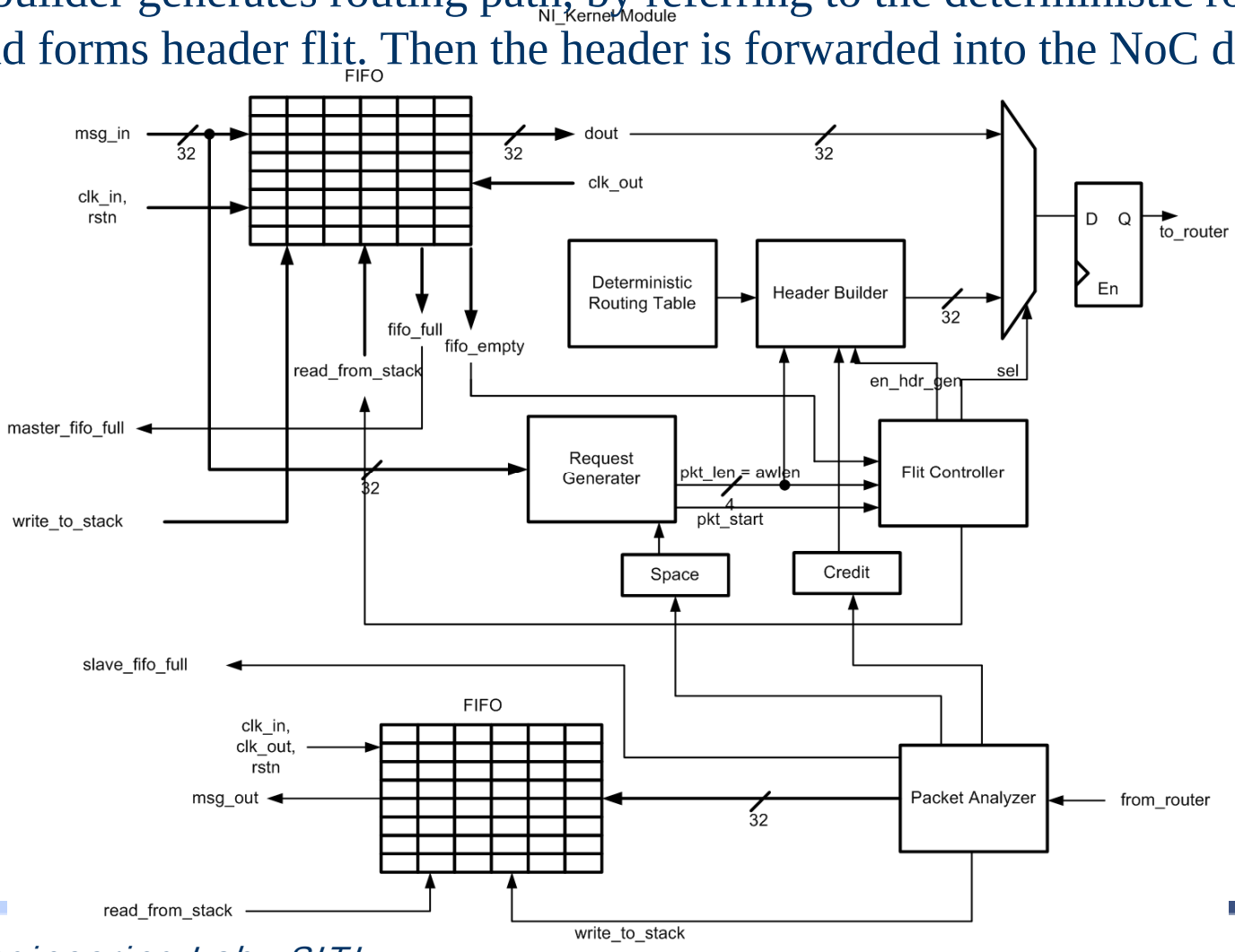
- Network Interface decouples computation and communication workload by translating the language CPU can understand (AMBA/AXI signals), into the language of router (header flit followed by packet body flits), and vice versa.





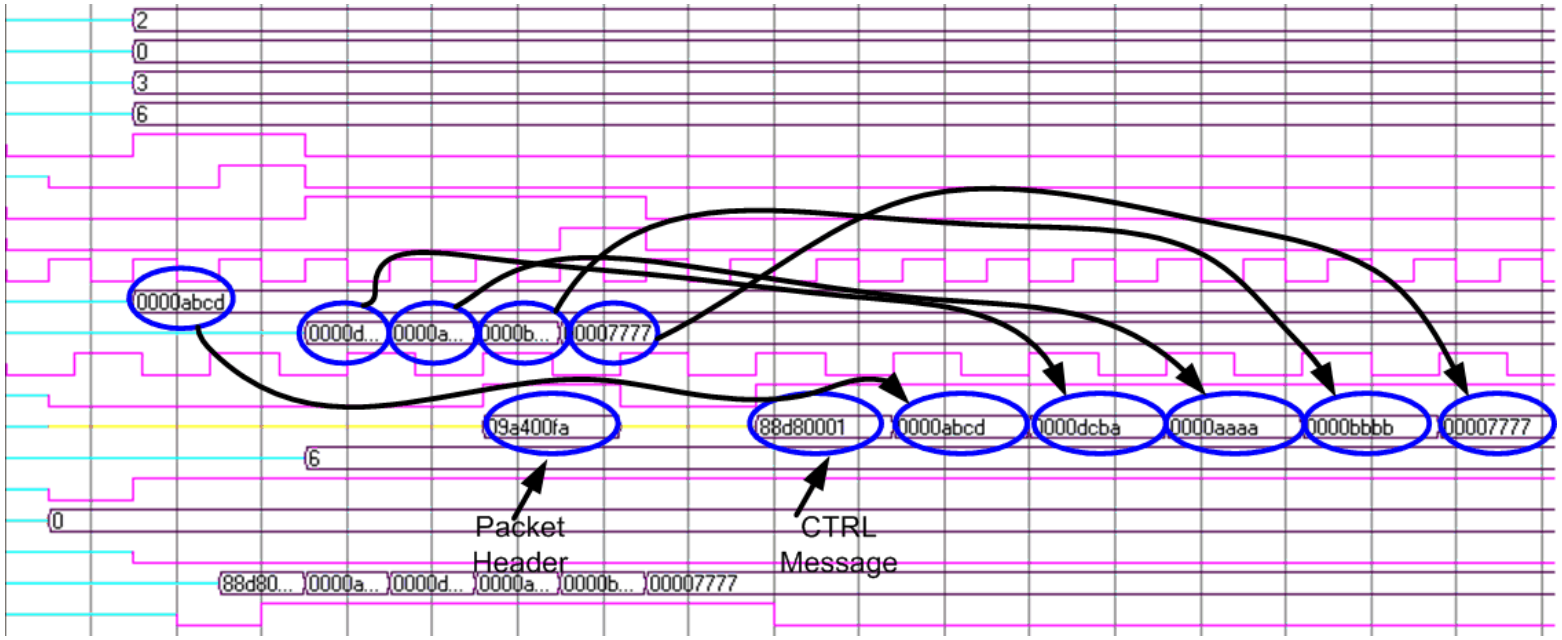
Network Interface

- Message is forwarded from FIFO to request generator, on its arrival. Then the h eader builder generates routing path, by referring to the deterministic routing ta ble, and forms header flit. Then the header is forwarded into the NoC domain.



Network Interface

- Following waveform shows a waveform of Verilog simulation of our NI. Simulation parameters are as follows-ARM core clock: 100MHz, NoC clock: 75MHz, Burst length: 4, flit width: 32bits, BUS width: 32bits, Burst mode: INCREMENT. This waveform says that the system delays of packet header and body flit generation processes are 40ns and 70ns, respectively



Conclusion

- TKIP cryptosystem is mapped onto the 9x9 torus NoC.
- A compact NI, equipped with AXI ports, is proposed.
- A SystemC simulation model is written to verify the proposed system.

Thanks!

Bit Engineering Lab.

Appendix

Bit Engineering Lab.

Message Integrity Code (MIC)

- Cryptographic checksum used in the handshaking process.
- The MAC value protects both a message's integrity as well as its authenticity, by allowing verifiers (who also possess the secret key) to detect any changes to the message content.
- This effort is against an attack called ‘message forgery’
- In TKIP ‘Michael’ is used, satisfying the bleeding edge of implementability of old WEP hardware
  - ✓ For better confidentiality, 802.11i standard recommends to use new CCMP (AES with SHA-1).

Input: Key (*K0*, *K1*) and padded MSDU (represented as 32-bit words) *M0*...*MN-1*
Output: MIC value (*V0*, *V1*)

MICHAEL((*K0*, *K1*) ,(*M0*,...,*MN*))
(*l*,*r*) ← (*K0*, *K1*)
for *i* = 0 **to** *N*–1 **do**
l ← *l* ⊕ *Mi*
(*l*, *r*) ← *b*(*l*, *r*)
return (*l*,*r*)

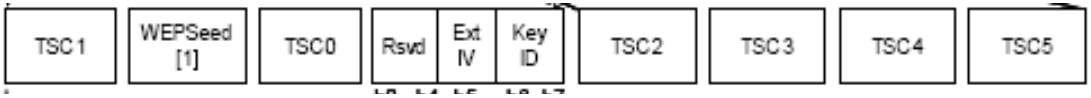
MIC generation algorithm

Input: (*l*,*r*)
Output: (*l*,*r*)
b(L,R)
r ← *r* ⊕ (*l* <<< 17)
l ← (*l* + *r*) mod 232
r ← *r* ⊕ XSWAP(*l*)
l ← (*l* + *r*) mod 232
r ← *r* ⊕ (*l* <<< 3)
l ← (*l* + *r*) mod 232
r ← *r* ⊕ (*l* >>> 2)
l ← (*l* + *r*) mod 232
return (*l*, *r*)

‘Michael’ pseudocode

Initialization Vector (IV)

- **A replay attack:** A form of network attack in which a valid data transmission is maliciously or fraudulently repeated or delayed.
- To prevent a replay attack we should use a session token which is dedicated to only one transaction
- In TKIP, the session token is IV (Initialization Vector)
  - ✓TKIP constitutes a session token from Transmit Sequence Counter (TSC)
  - ✓The TSC is implemented as a 48-bit monotonically incrementing counter, initialized to 1 when the corresponding TKIP temporal key is initialized or refreshed.



Extended IV

Integrity Check Value (ICV)

- Integrity Check Value is constructed from CRC-32 value of the decrypted payload and MIC.
- Drop packet if the ICV of {payload, MIC} isn't bitwise accurate.
- MIC is applied to each MSDU, while ICV is applied to each MPDU, which is fragmented {MSDU, MIC}
- WEP ICV helps to prevent false detection of MIC failures that would cause countermeasures to be invoked.

Compromising Weak Key

- In WEP, Per-packet key is constructed from concatenation of IV and base-key.
- If the encrypted plain-text includes known sequence, the confidentiality of the key is easily broken.
- Therefore, TKIP adopted a multi-level key management scheme.
- Compute the per-packet key by cryptographically mixing TA (Transmit Address), IV, base key
  - ✓ Encrypt ({Data, MIC, ICV})
  - ✓ With Key_Generator ({TA, IV, base_key})
- Mixing function is a Feistel cipher designed by Doug Whiting and Ron Rivest
  - ✓ De-correlate IV and per-packet key
  - ✓ Feistel cipher:
    - A sort of block cipher that combines multiple rounds of repeated operations, such as Bit-shuffling, Simple non-linear functions, Linear mixing using XOR