ShieldUS: A Novel Design of Dynamic Shielding for Eliminating 3D TSV Crosstalk Coupling Noise

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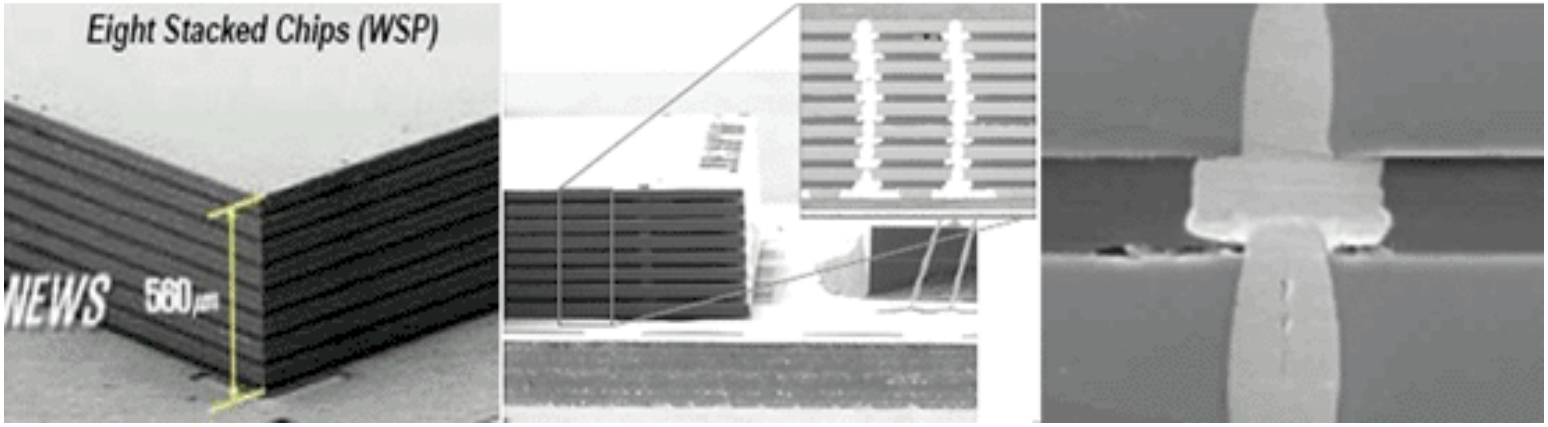
Outline

- **Introduction**
  - **Motivation**
  - **Review of Crosstalk**
  - **Contribution**
- **3D Crosstalk Model**
- **ShieldUS**
- **Evaluation**
- **Conclusion**

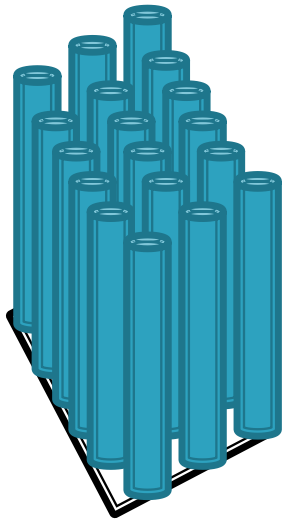
Introduction

- **3D IC is a promising technology to meet**
  - **High throughput, high scalability**
- **TSVs (through silicon vias) are used to connect different dies in 3D chips**

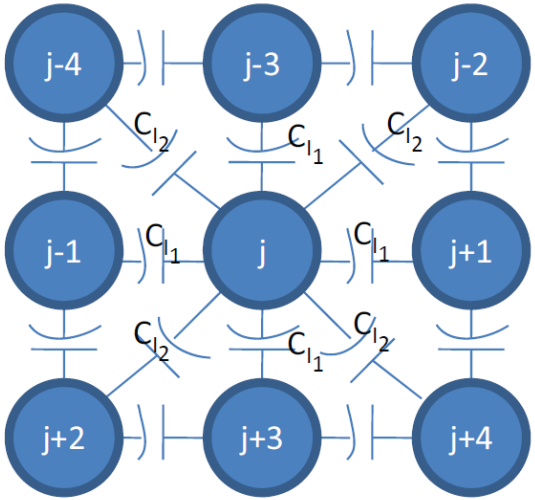


Eight Stacked Chips by Samsung

Introduction



- **TSVs are usually bundled together**
  - **Provide high memory bandwidth**
  - **Cause the crosstalk coupling noise effect!**
- **Crosstalk coupling noise is a fundamental problem in VLSI design**
  - **May lead to performance degradation**
  - **More complicated in 3D Chip!**

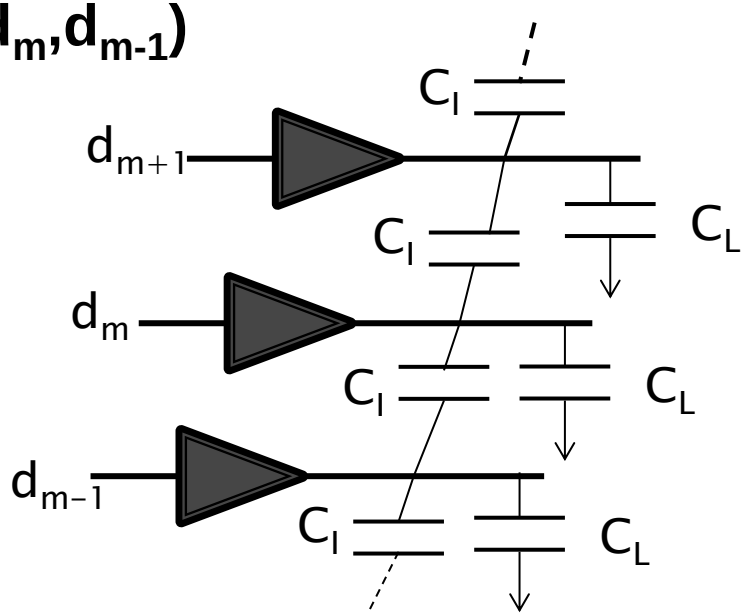


Review of Crosstalk

- **Crosstalk: a signal transmitted on one circuit creates an undesired effect on another circuit**
  - **Usually caused by undesired capacitive, inductive, or conductive coupling from one circuit.**
- **The coupling effects can be calculated by considering the dominant capacitance**
- **The signal delay can be derived by the coupling effects.**

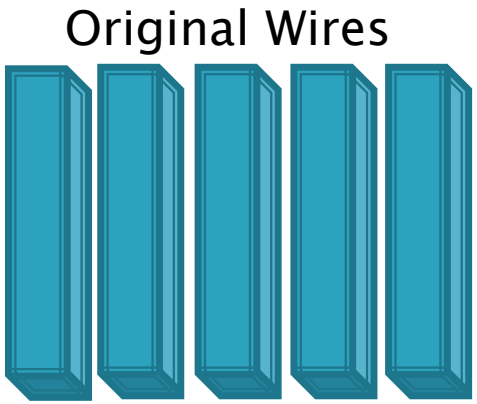
Review of Crosstalk

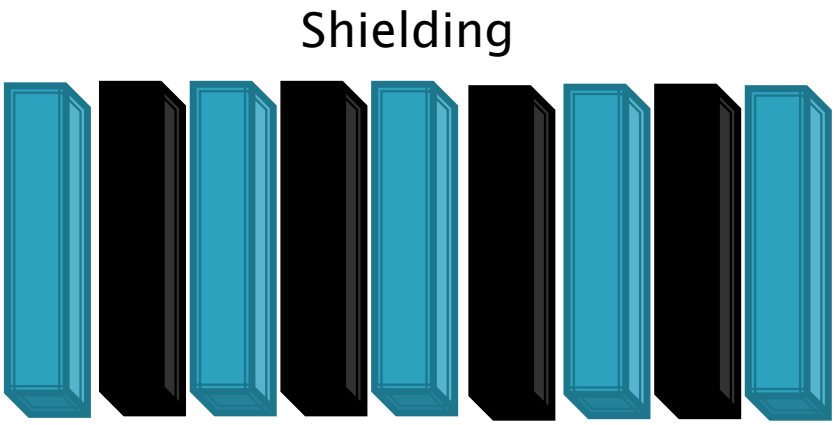
- **The coupling effects is also affected by the transitions.**
  - **The opposite transitions → Slow down**
    - **Ex: 0→1, 1→0,0→1 (d_{m+1},d_m,d_{m-1})**
  - **The same transitions → Speed up**
    - **Ex: 0→1, 0→1,0→1 (d_{m+1},d_m,d_{m-1})**

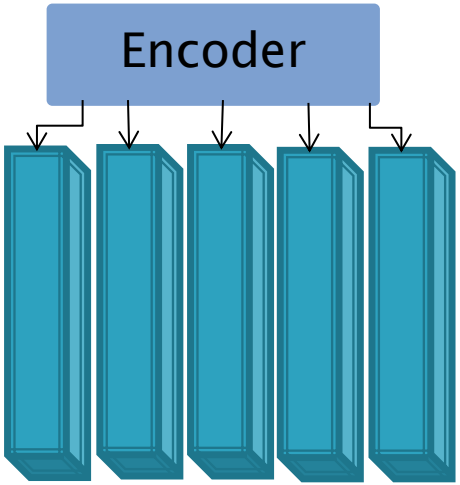


Review of Crosstalk

- **Common solutions**
  - **Shields insertion**
    - **Too many redundant wires**
  - **Crosstalk avoidance coding**
    - **High coding complexity**







Introduction

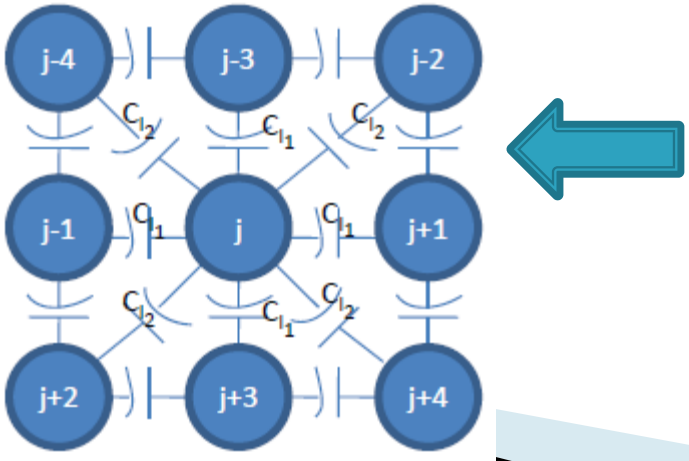
- **In this paper, we**
  - **Infer a 3D crosstalk noise model**
  - **Propose a novel runtime data-to-TSV remapping mechanism, called ShieldUS**
  - **Have up to 12% performance improvement after applying ShieldUS in the experiment results**

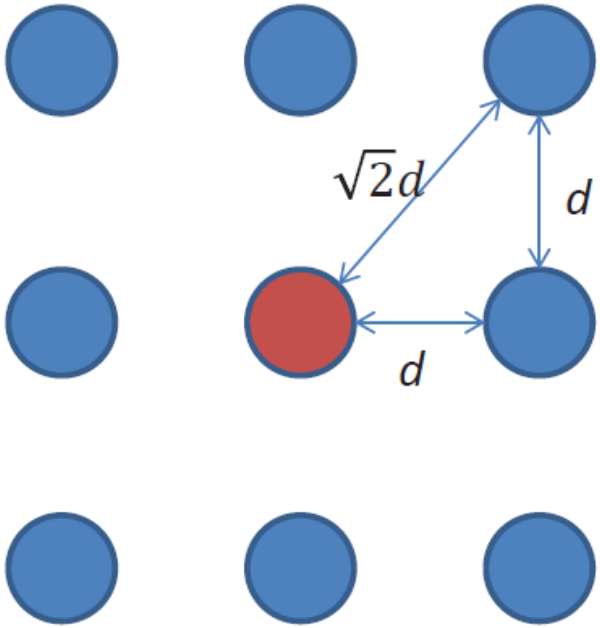
Outline

- Introduction
- 3D Crosstalk Model
- ShieldUS
- Evaluation
- Conclusion

3D Crosstalk Model

- **In 3D case, the crosstalk effects from all the neighbors are necessary to be calculated**
- **There are two categories of interfering TSVs**
  - **The direct neighbors**
    - **The distance is d**
  - **The diagonal neighbors**
    - **The distance is $\sqrt{2}$d**

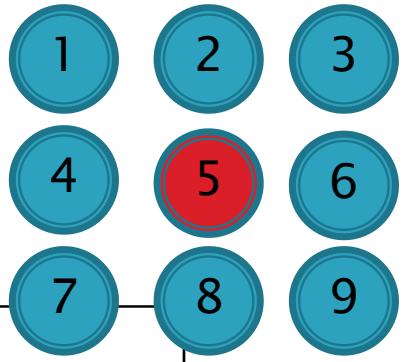




3D Crosstalk Model

- **The classes of signal delay of TSVs can be derived by Ohm's law**

λ1 is related to direct neighbor
λ2 is related to diagonal neighbor



Class	C_{eff}	Transition patterns
1	C_L	$000000000 \rightarrow 111111111$
2	$C_L(1+\lambda_2)$	$011111111 \rightarrow 000000000$
3	$C_L(1+\lambda_1)$	$101111111 \rightarrow 000000000$
4	$C_L(1+2\lambda_2)$	$010111111 \rightarrow 000000000$
5	$C_L(1+\lambda_1+\lambda_2)$	$001111111 \rightarrow 000000000$
6	$C_L(1+2\lambda_1)$	$101011111 \rightarrow 000000000$
⋮		
81	$C_L(1+8\lambda_1+8\lambda_2)$	$000010000 \rightarrow 111101111$

Outline

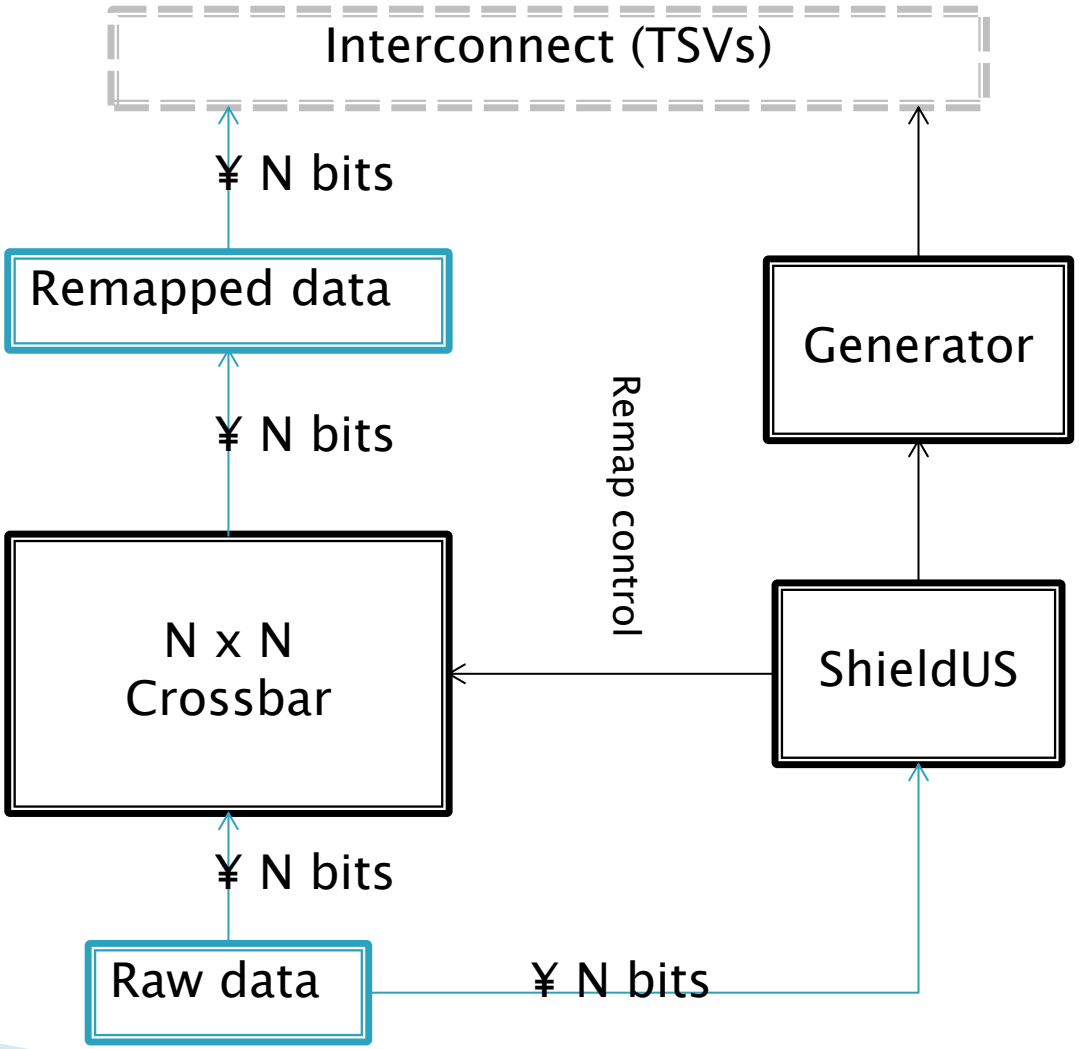
- Introduction
- 3D Crosstalk Model
- ShieldUS
  - Overview
  - Mechanism
- Evaluation
- Conclusion

ShieldUS

- **Goal**
  - **Minimize the occurrence of higher class transmissions &**
  - **Maximize the occurrence of lower class transmissions**
- **Key idea**
  - **Shielding &**
  - **Dynamic Data-to-TSVs remapping &**
  - **Variable cycle transmission [7]**

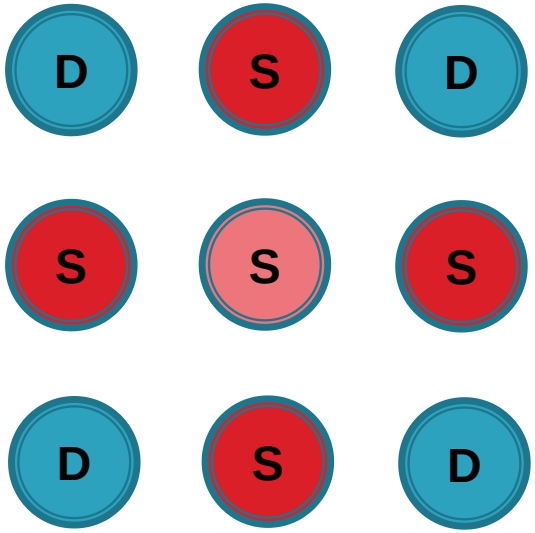
[7] L. Li, N. Vijaykrishnan, M. Kandemir, and M. Irwin. A crosstalk aware interconnect with variable cycle transmission, DATE'04

ShieldUS


Interconnect (TSVs)
¥ N bits
Remapped data
¥ N bits
N x N
Crossbar
¥ N bits
Raw data
Remap control
Generator
ShieldUS
¥ N bits

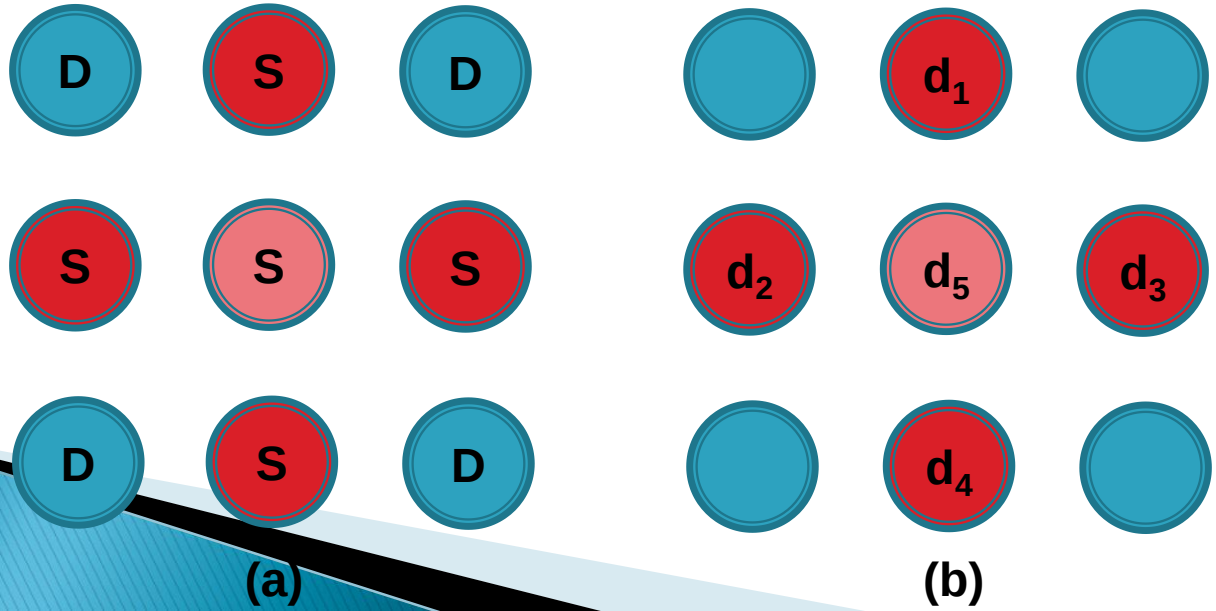
Shielding

- **In 3x3 TSVs, there are 4 data TSVs and 5 shields**
  - **It can be generalized to any *NxN array***
  - **The crosstalk caused by center TSV is relatively weak**



Dynamic Data-to-TSVs Remapping

- **Check the data similarity in a given period and rank them**
  - **The top 4 with the highest similarity are mapped to the shield cells**
  - **The fifth one is mapped to the center cell**



Variable Cycle Transmission

- **To avoid crosstalk, the cycle length will be decided based on the worst noise class**
  - **The signal delay is not as long as the worst class in most time**
- **Since the noise class varies in different periods, the variable cycle transmission is used**
  - **Multiple short clock cycles are used instead of using a long single cycle**
  - **Precalculate the required number of cycles of each noise degree before sending data**

Interval Equilibration Unit (IEU)

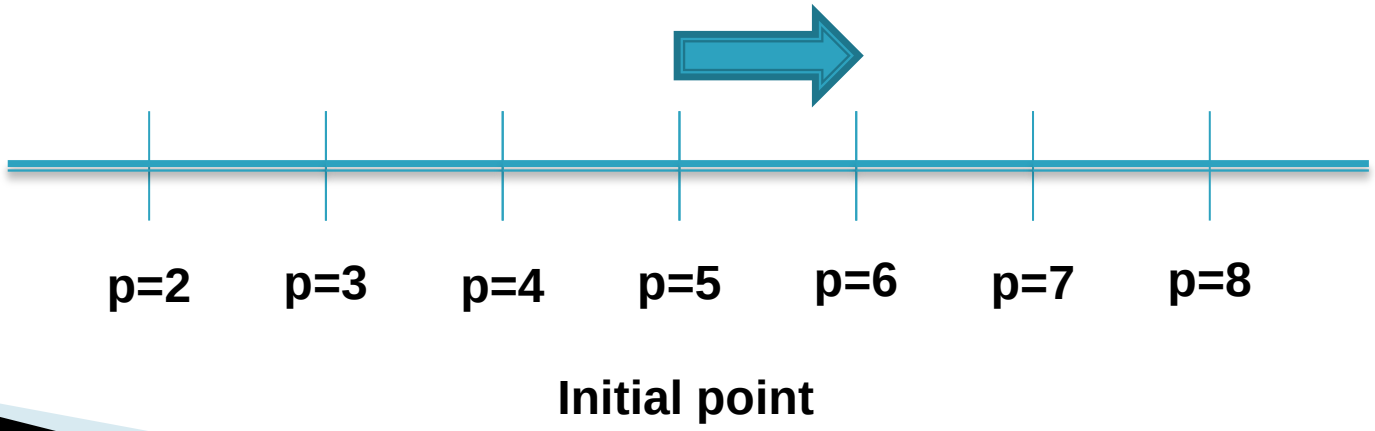
- **The remapping procedure is operated every *I* cycles, but setting a fixed interval is not practical**
  - **Each program has their own program behaviors**
- **IEU is proposed into the dynamic shielding.**
  - **The idea is similar to Sandwich theorem**

Interval Equilibration Unit (IEU)

- In IEU, the initial interval is C^p
- C is a user defined base number
  - Identify the aggressiveness of each trial
- P is the number for exponentially increasing or decreasing the base number
  - Depend on whether previous adapting interval has gained benefits or not
- We use the average noise class to evaluate

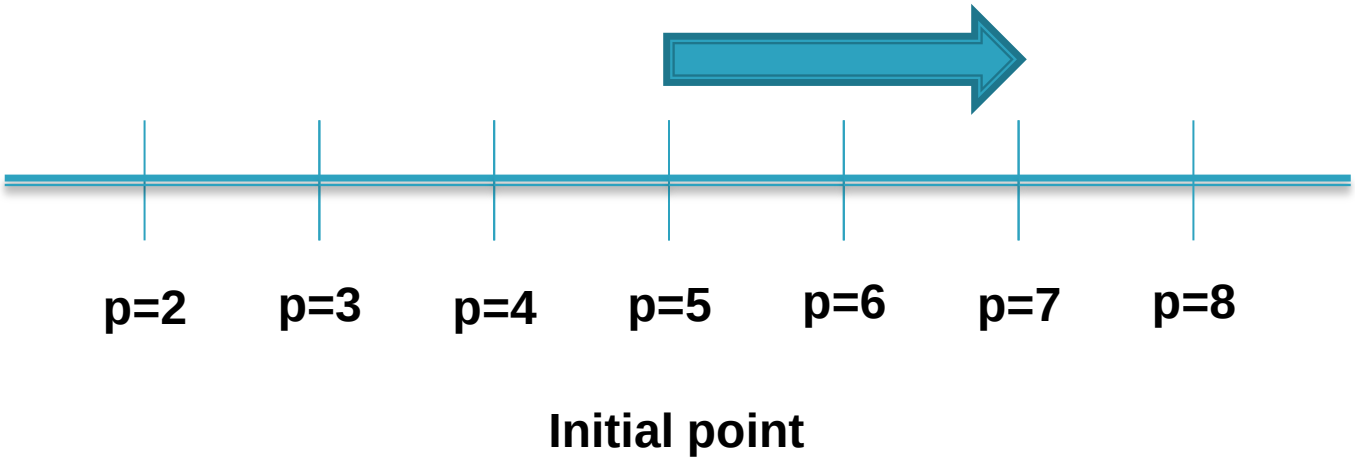
Interval Equilibration Unit (IEU)

- In this example, the initial interval is 10^5
- In the beginning, we set interval as the initial interval
- Step1:
  - After the first interval passes, IEU tries to increase interval to 10^6 to explore the similarity



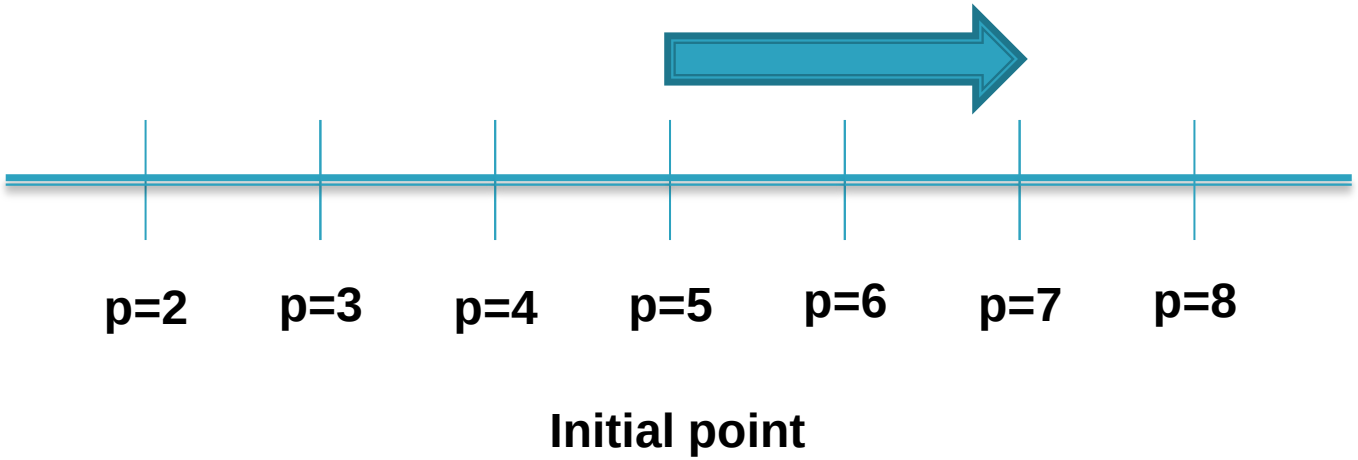
Interval Equilibration Unit (IEU)

- **Step2:**
  - **The average noise class of 10^6 is better than 10^5**
  - **IEU continues to increase interval to 10^7 to explore the similarity**



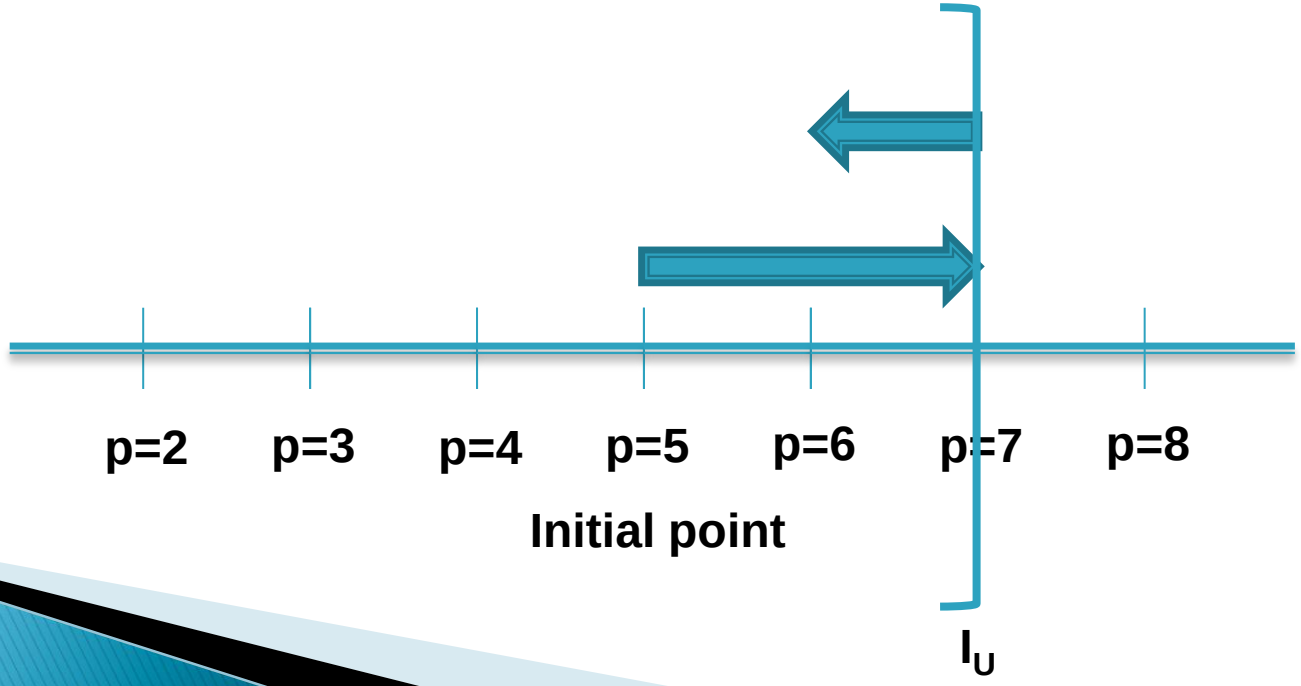
Interval Equilibration Unit (IEU)

- **Step3:**
  - **The average noise class of 10^7 is not better than 10^6**
  - **IEU gives 10^7 one more chance**



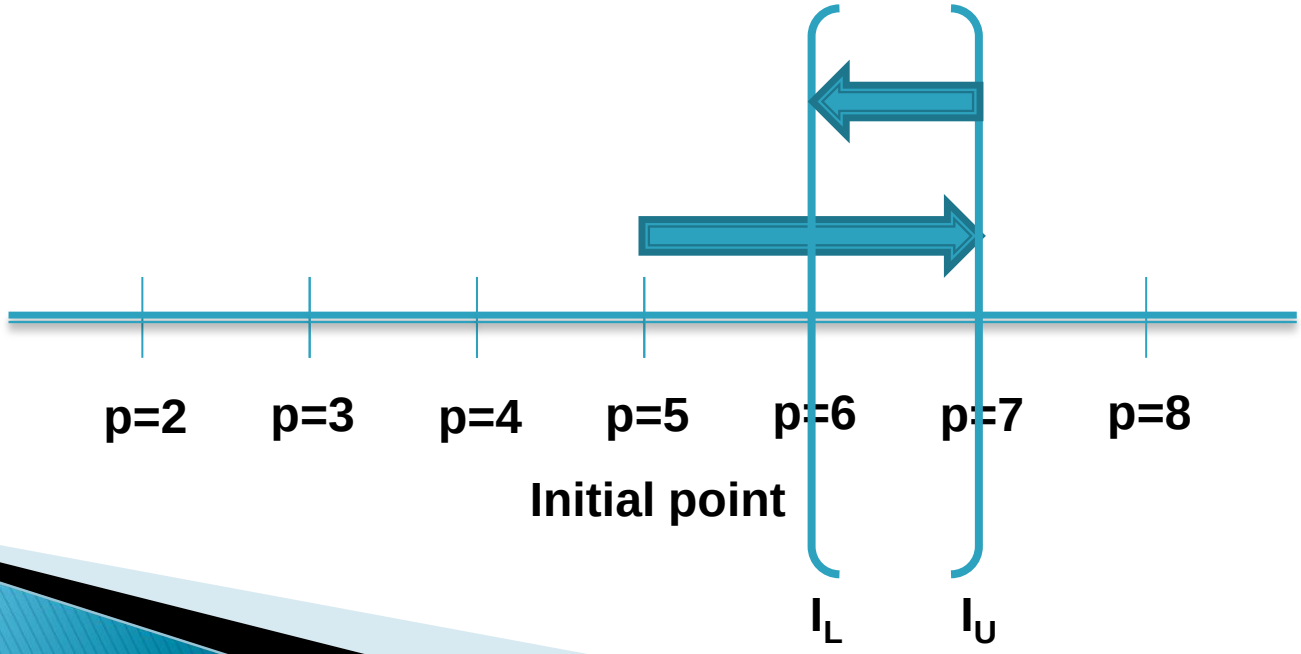
Interval Equilibration Unit (IEU)

- **Step4:**
  - **The average noise class of 10^7 is not better than 10^6 again**
  - **IEU sets upper bound to 10^7**
  - **IEU decreases interval from 10^7 to 10^6**



Interval Equilibration Unit (IEU)

- **Repeat the same procedure, the lower bound can be found**
- **The interval is decided, while the lower bound and upper bound are overlapped**



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Evaluation

- **Settings**
  - **49 TSVs are arranged by a 7x7square**
  - **82 noise classes are divided into 5 groups**
    - **$Group_1$=(0,10), $Group_2$(11,30), $Group_3$(31,55), $Group_4$(56,74) and $Group_5$(75,82)**

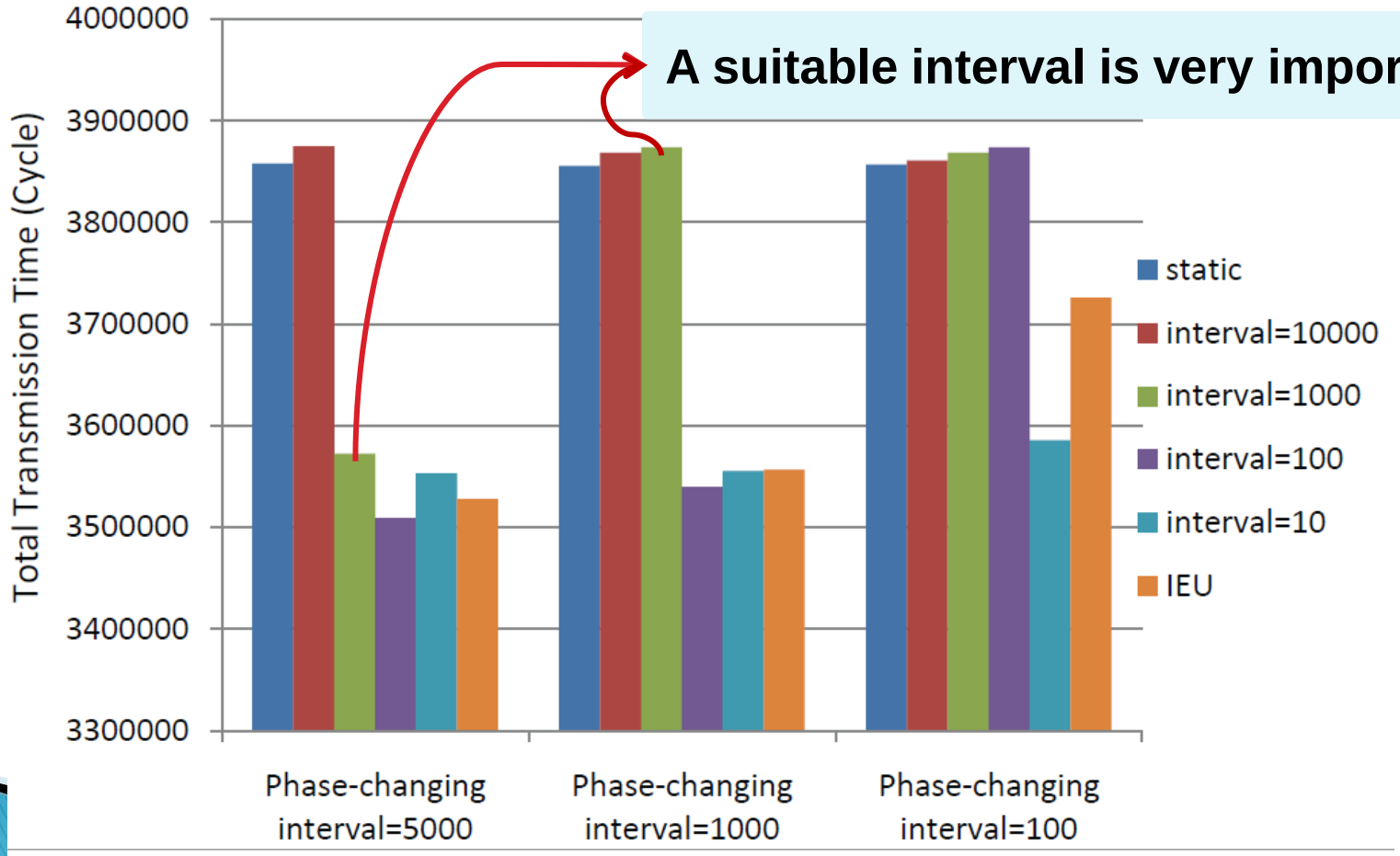
Parameter	Technology notes
Technology	45nm
Width (nm)	102.5
Space (nm)	102
Thickness (nm)	235.75
Height (nm)	215.25
Dielectric constant	2.3

Mechanism Validation

- **We validate the mechanism of ShieldUS with synthesized traffic**
  - **Periodically select 16 of them to have higher transition probability, and 33 of them have lower transition probability.**
  - **The transition probabilities change with different phase-changing intervals**

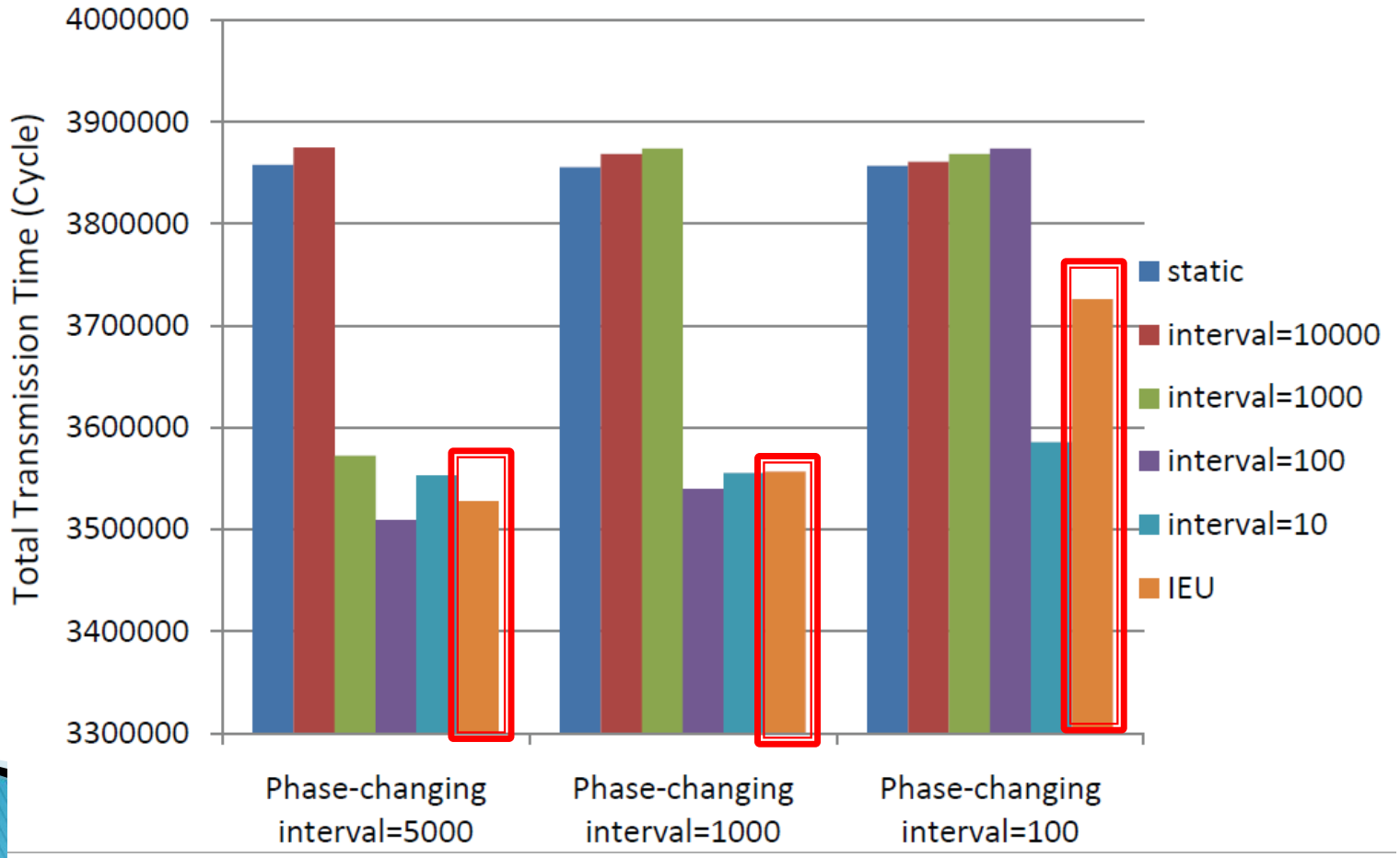
Mechanism Validation

ShieldUS has the ability to learn the patterns from history and successfully selects the suitable bits as shields



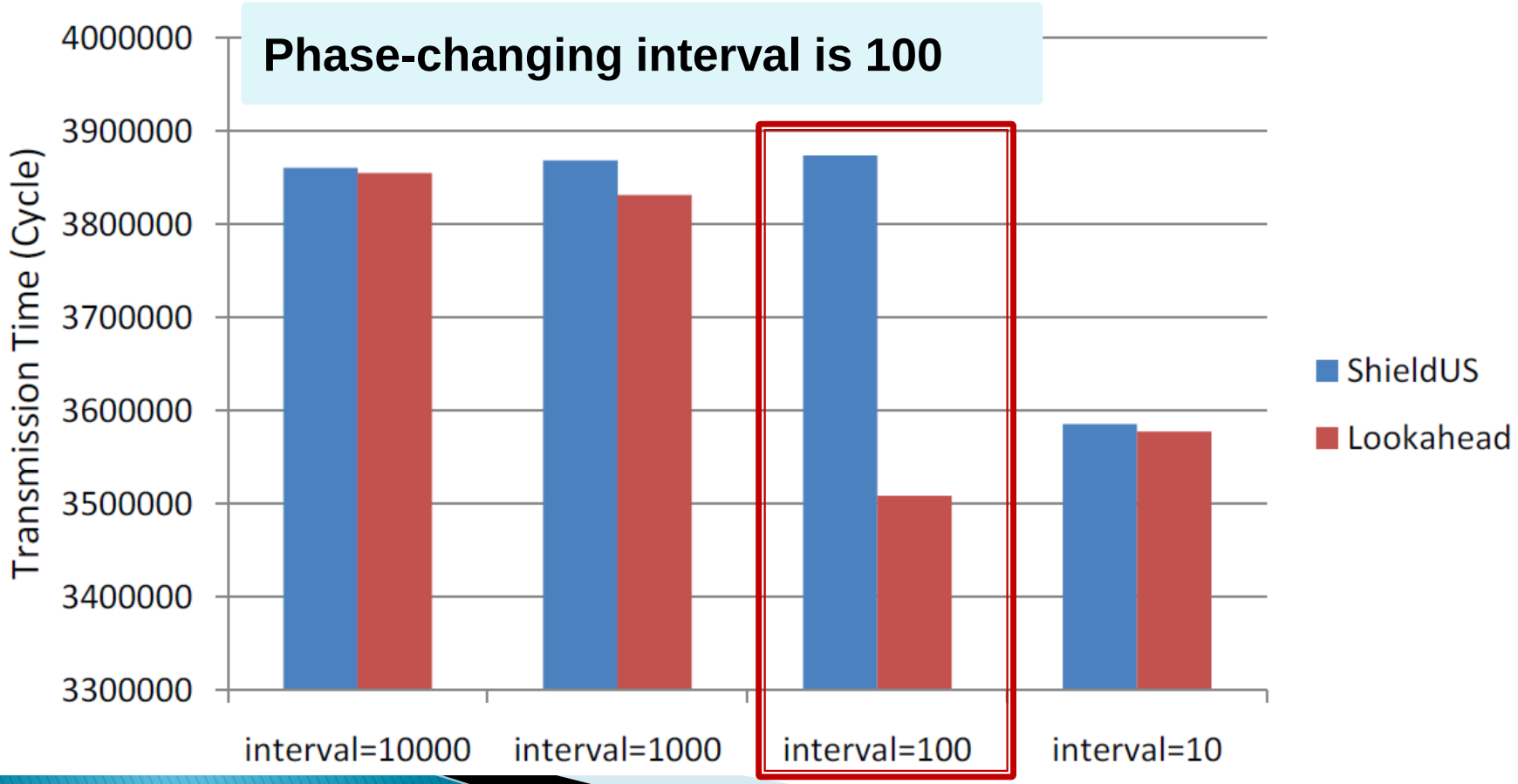
Mechanism Validation

IEU are the best or the second best in all the cases and improved by 8.5% compared with static mapping.



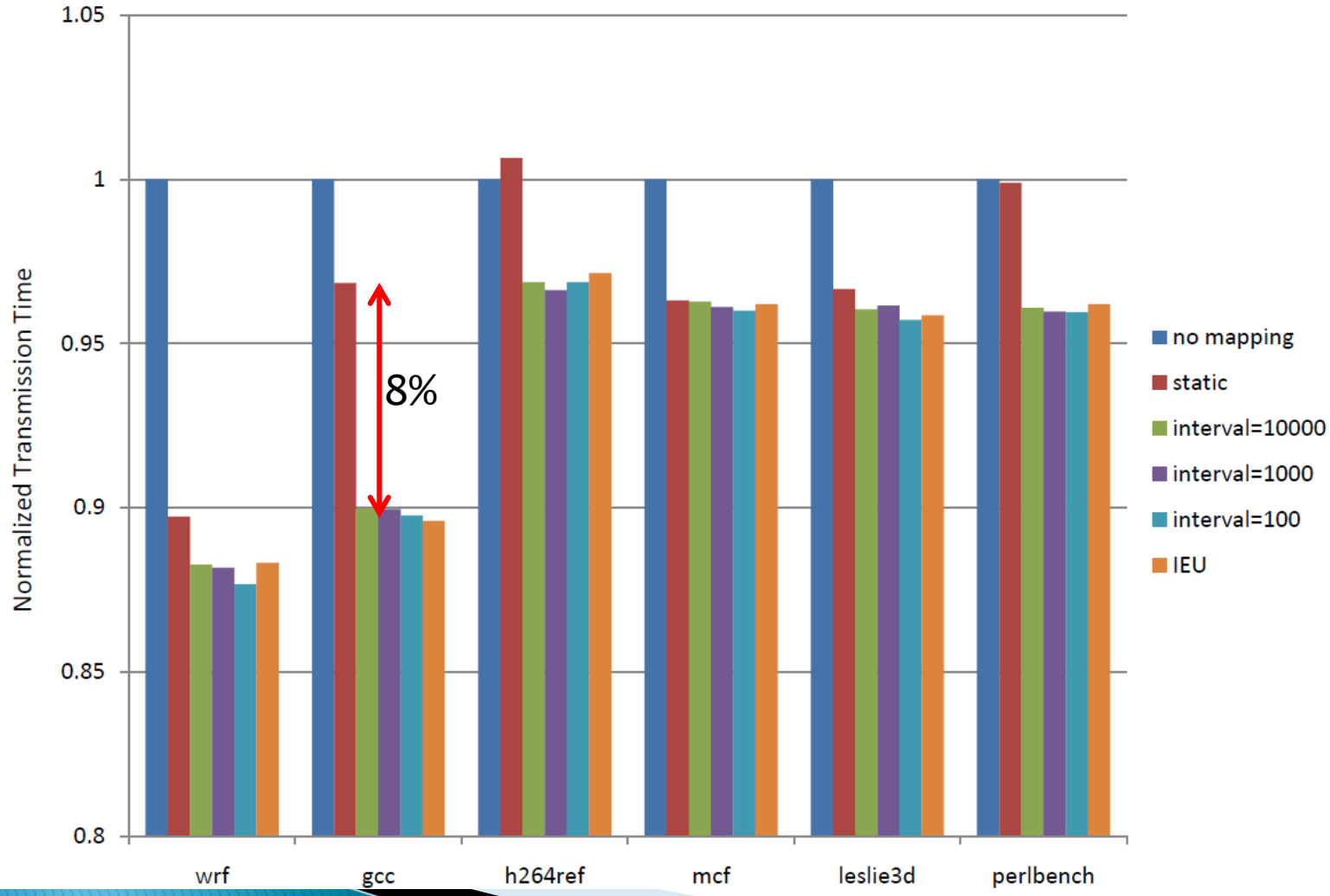
Comparison with Oracle Method

An oracle method is used to look ahead the incoming traffic in advance.



Real Benchmark Evaluation

We capture the data transitions in address bus line from real benchmark



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Conclusion

- **In this paper, we**
  - **Firstly discuss the 3D crosstalk coupling noise model**
  - **Propose *ShieldUS,* a novel runtime *data-to*-TSVs remapping mechanism**
- **Future work**
  - **Consider a two-stage crossbar to eliminate the overhead.**
  - **The details of the implementation are going to be discussed**

Q &A