Systems Modelling & Simulation

Grid Computing (M)

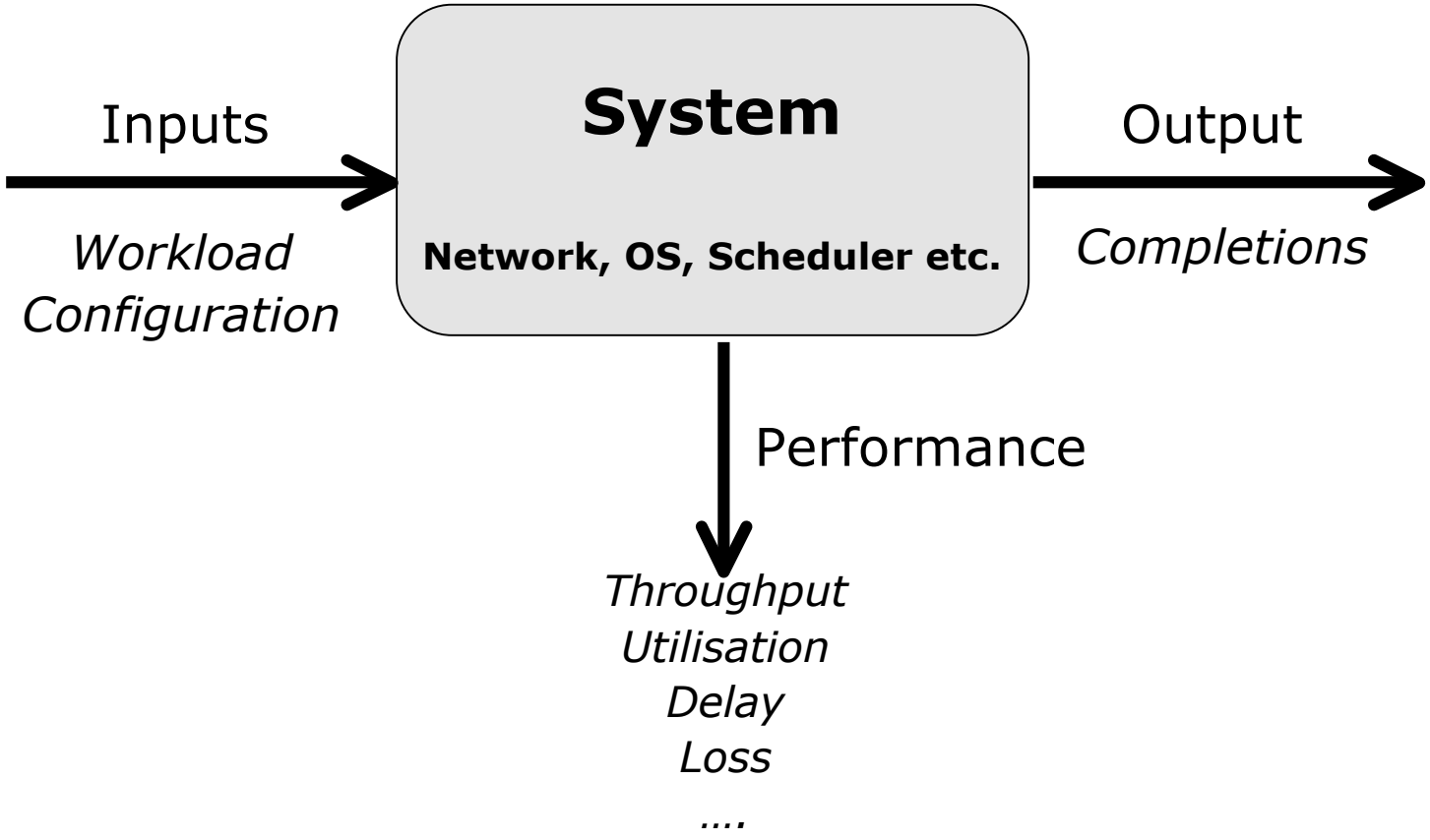
Lecture 17

Olufemi Komolafe (femi@dcs.gla.ac.uk)

March 2006



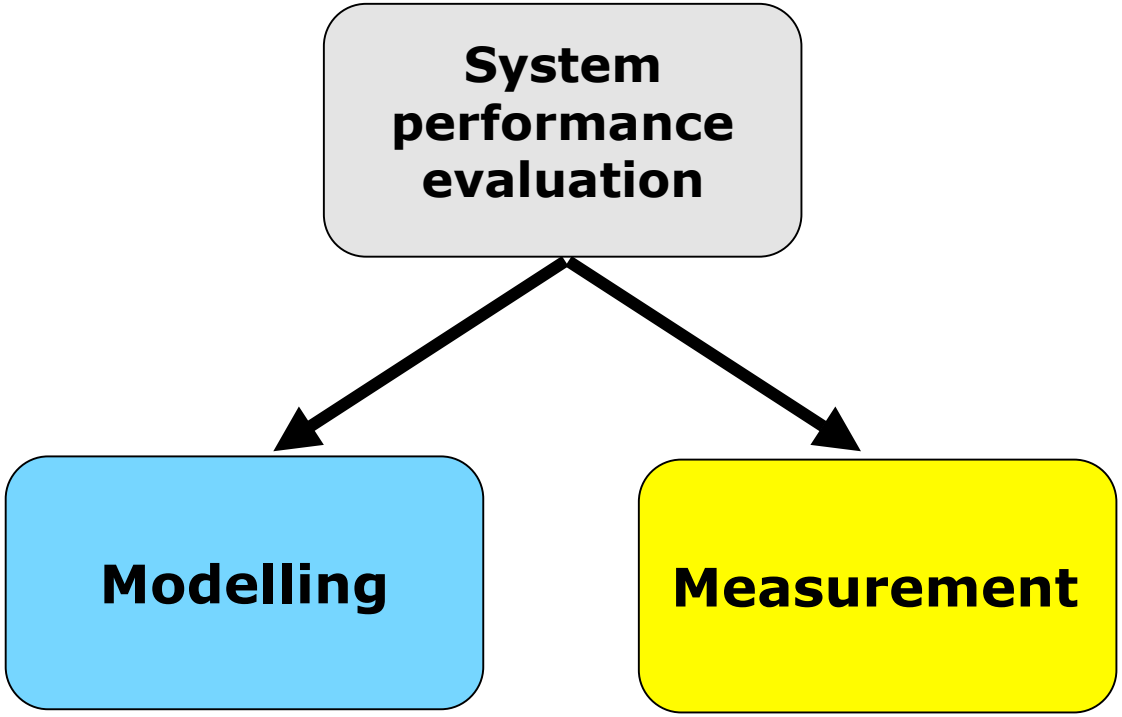
Overview



How can system performance be evaluated?

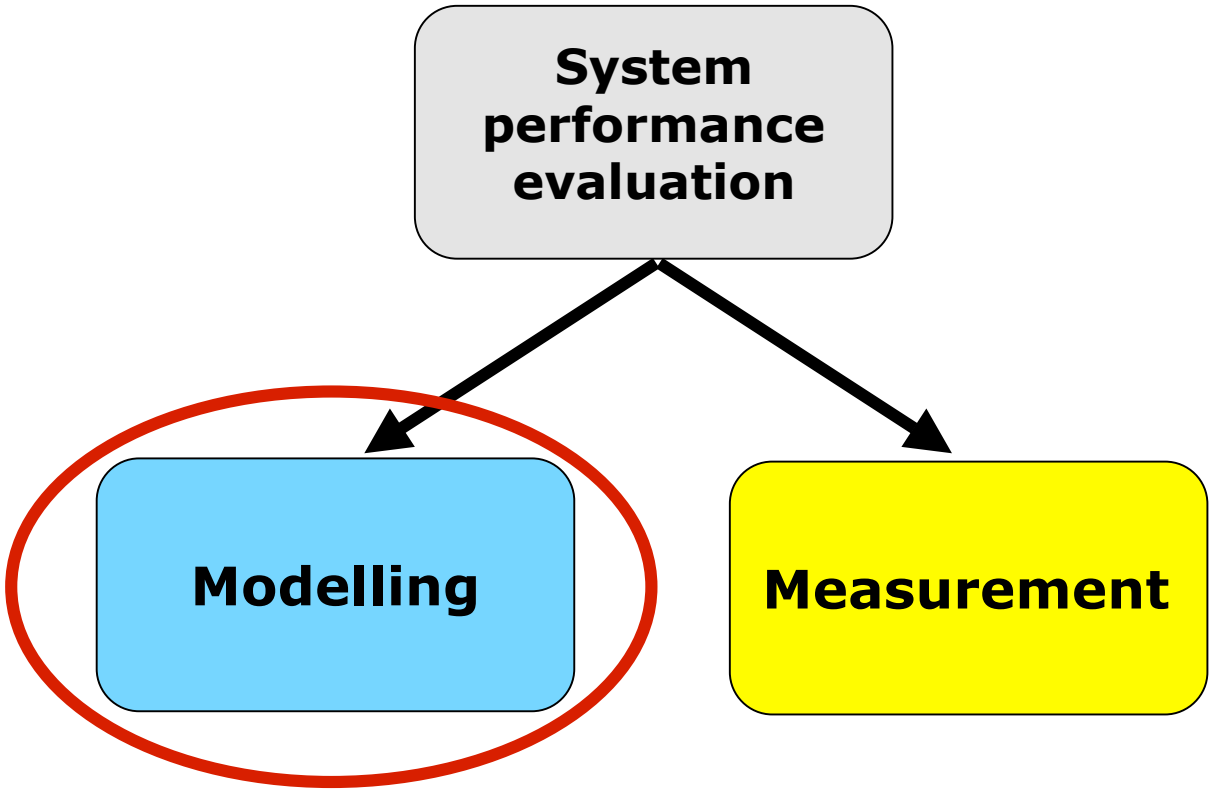
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System Performance Evaluation Choices



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System Performance Evaluation Choices



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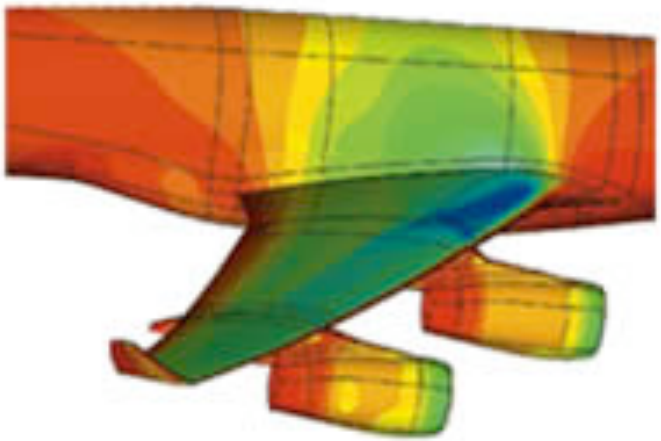
Modelling Popular as Measurement may be..

- **Disruptive**
  - Measuring phenomena without changing it?
    - Heisenberg Uncertainty Principle?
    - Does a tree falling in the forest make any noise if no one is there to hear?
- **Dangerous**
  - Typically interested in "failure conditions"/"stress testing"
    - How quickly will building be evacuated in a large fire?
    - At what depth will water pressure crush submarine hull?
    - At what traffic load will DCS network "collapse"?
- **Expensive**
  - Typically requires specialised equipment, lengthy measurement periods, significant people-hours etc.
- **Impractical**
  - Insurmountable technical, logistical, ethical, legal etc. barriers
- **Ad hoc**
  - How applicable is specific measurement in generic case?
- **Impossible**
  - System not yet built/implemented/deployed
    - i.e. wanting to justify system design ⇒ ***predict*** performance

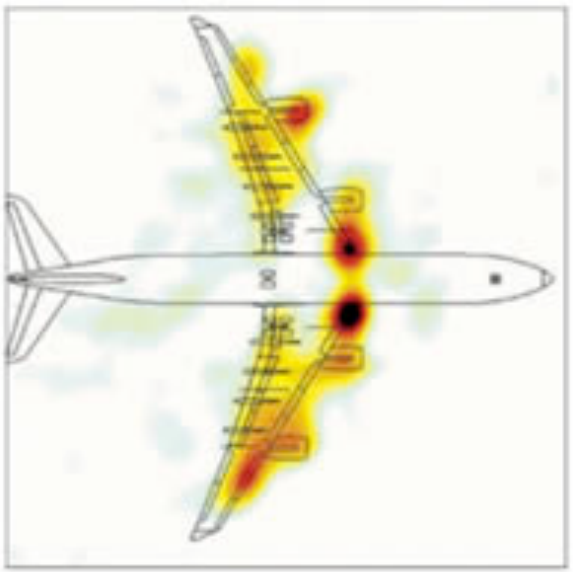
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Modelling & Measurement

Not necessarily mutually exclusive....







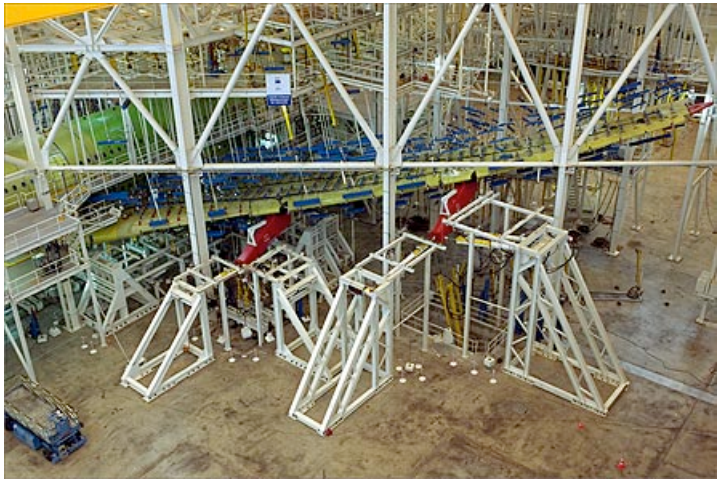


Sources: www.onera.fr, www.airliners.net, www.airbus.com

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Modelling & Measurement

Not necessarily mutually exclusive….









Sources: www.onera.fr, www.airliners.net, www.airbus.com

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Modelling & Measurement

Discrepancies between models & reality....

Airbus' 'big baby' is too big
July 17, 2004

A380 is still overweight by as much as 4 metric tons, hurting efficiency

Lifting a curtain at a new Airbus SAS factory near here in May, Chief Executive Noel Forgeard unveiled a two-story aircraft with a 261-foot wingspan: "Our big baby," he told his 4,000 guests.

But it's bigger than the parent expected.

Six months before flight tests and less than a year before its first scheduled public flight in June 2005, the A380 is still overweight by as much as 4 metric tons, said Tim Clark, president of its biggest customer, Emirates, the Middle East's largest carrier.

Reuters

Airbus A380 Wing Ruptures In Static Test
February 16, 2006

Airbus said on Thursday a wing for its A380 superjumbo suffered a "rupture" during stress tests in a factory at its headquarters but said it did not expect the incident to delay first deliveries.

"There was a rupture... the incident happened when it was going from 1.45 to 1.50 (times) its limit load," an Airbus spokesperson said.

She said the company was pleased with testing overall and did not expect the incident to delay the plane's type certification due later this year ahead of its first delivery to Singapore Airlines.

One of the test A380 aircraft is set to fly at the Asian Aerospace air show in Singapore next week.

Reuters

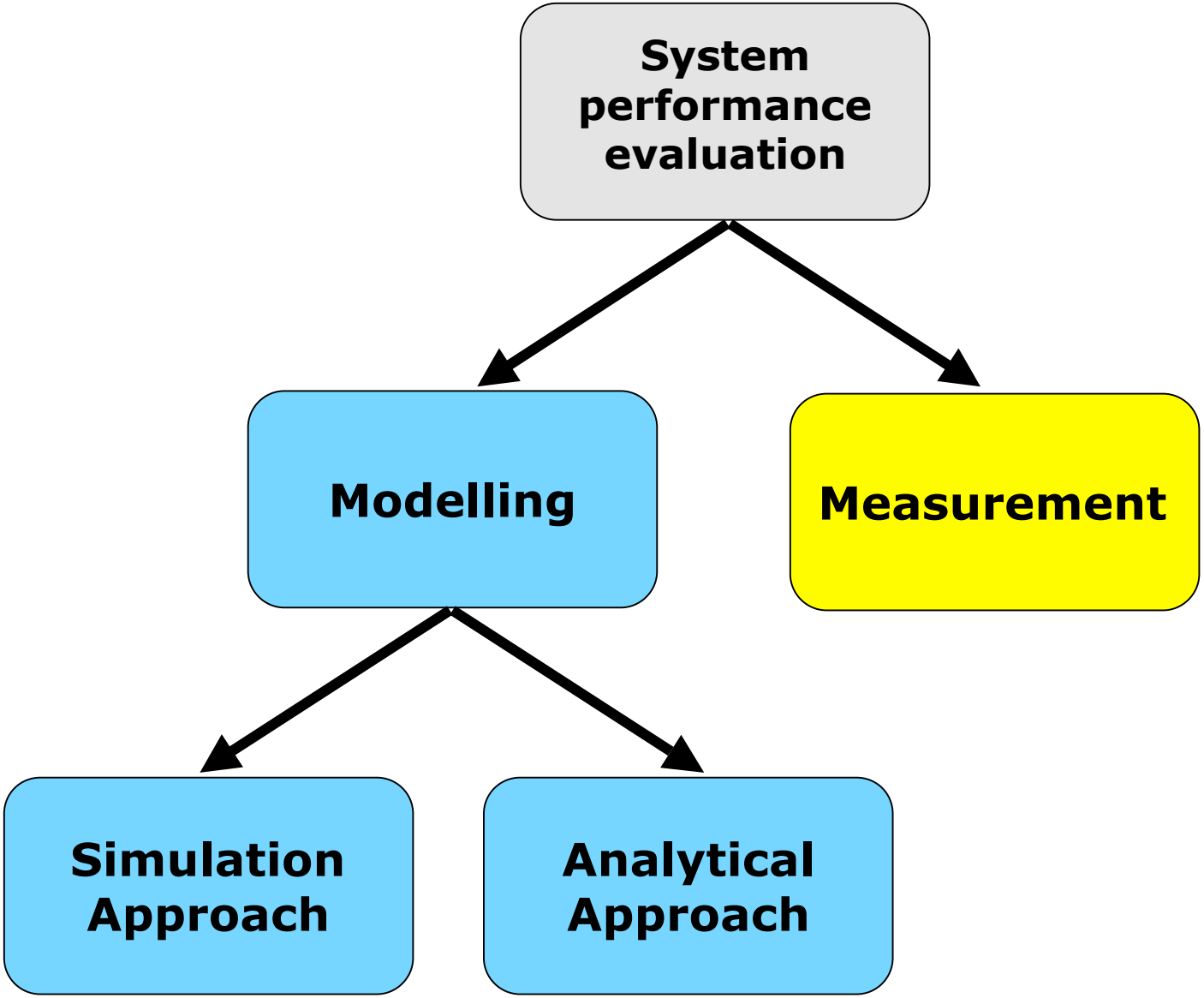
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Some Intuitive Observations

- Lots of different ways to model a system
  - No "right" answer but decision informed by
    - Metric(s) of interest
    - Desired level of abstraction/detail & accuracy
    - Technical, financial, time, personnel constraints
    - Convention
- Good models mimic reality closely
  - Minimising discrepancy between model & reality crucial
- Modelling typically includes a trade-off between complexity/detail & time/effort to produce output

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System Performance Evaluation Choices



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Aside…… Good Exemplar Papers

Measurement

On the Self-Similar Nature of Ethernet Traffic

W. E. Leland, M. S. Taqqu, W. Willinger, D. V. Wilson

Proc. of ACM SIGCOMM 1993

Analytical Modelling

A Comparison of Hard-state & Soft-state Signaling Protocols

P. Ji, Z. Ge, J. Kurose, D. Towsley

Proc. of ACM SIGCOMM 2003

Simulation Modelling

Stability Issues in OSPF Routing

A. Basu, J. G. Riecke

Proc. of ACM SIGCOMM 2001

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Approaches to Modelling

	Simulation Approach	Analytical Approach
Based upon	Algorithmic abstraction of system	Mathematical abstraction of system
System performance evaluated by	"Executing" code	"Solving" equation
Advantages	Greater level of detail possible Greater scalability Accessible to "anyone"	Requires thorough understanding of maths, stats, system etc. More elegant
Disadvantages	Verification & validation often omitted Statistical reliability Significant run times "Opaque" papers "Garbage in garbage out"	Approximations & simplifications to avoid intractability Ad hoc solutions "Complex" papers "Garbage in garbage out"

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Simulating Communication Systems

Computer and communication systems are mostly

- Dynamic systems
  - Output may depend on older inputs and/or current time
- Stochastic systems
  - Random variable and/or random process used for part of input or internal variable
- Discrete time/discrete event systems
  - Countable number of state changes within any finite time interval
- Discrete state systems
  - State space is finite or countably infinite

Hence, **discrete event simulation** typically used

- Modifies model state only at discrete times, between which the state is guaranteed not to change

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Generating Random Variates

- True random numbers
  - Generated from real random source (e.g. Linux */dev/random*)
  - Cannot infer next value from values generated so far
- Pseudo-random numbers
  - Generated according to fixed algorithm
  - Can infer next number from previous ones
    - i.e. numbers not random but appear random to an external observer
  - Same seed always produces same sequence
    - Reproducibility aids debugging
  - Generates periodic sequence of numbers
    - Repeats sequence once all cycle complete
    - Length of cycle important factor to prevent undesirable correlation/bias

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Key Stages in Simulation Study

1. Define goals
2. Develop conceptual model
3. Develop simulation model
4. Test and refine simulation model
5. Make pilot runs
6. Make production runs
7. Validate simulation
8. Document

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Simulation Modelling

Simulator == complex computer program

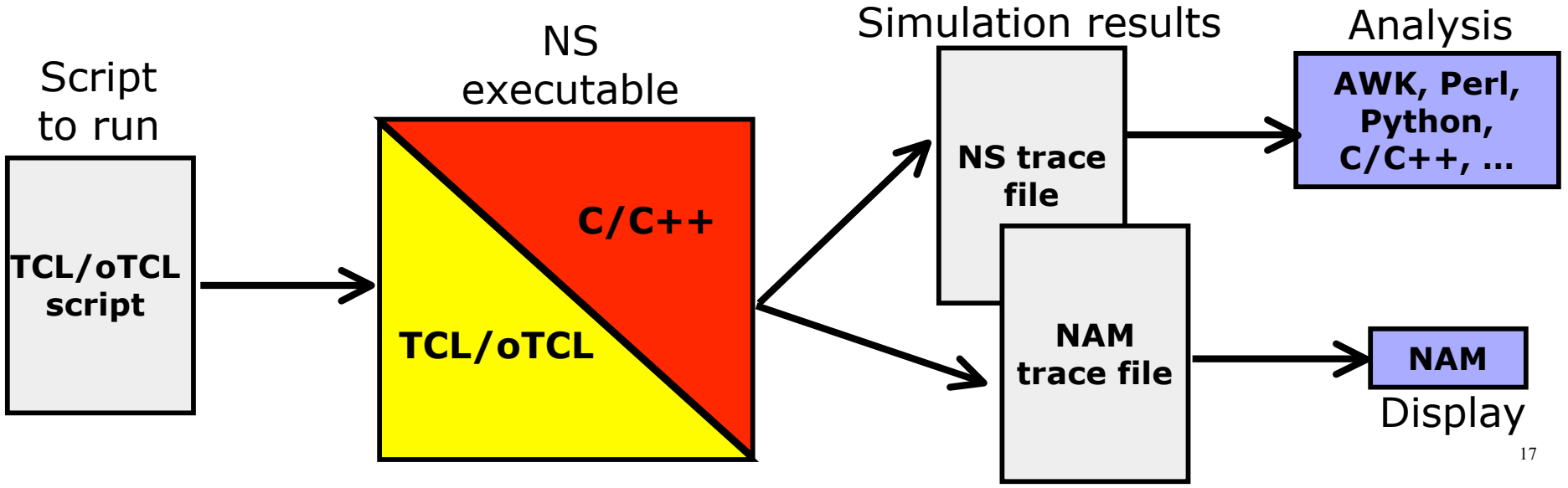
- Potentially written in any programming language
- 2 alternatives for developing simulator model
  - Write all code from scratch
    - i.e. system-specific code and generic simulation functions
  - Add system-specific code to existing simulator package
    - Wide range of packages exist: http://www.idsia.ch/~andrea/simtools.html
    - Focus efforts on system-specific code
    - Simulator package typically offers
      - Event scheduler
      - Clock & time management
      - Random number generator and accompanying statistical libraries
      - Numerous useful libraries
      - Dynamic memory management
      - Trace routines & GUI
      - Technical support/community of users

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Exemplar Simulation Package 1

NS-2 (http://www.isi.edu/nsnam/ns/)

- De-facto open source networking simulator
- Object-oriented packet-level discrete event simulator
- Modules for many TCP/IP protocols
- 2 languages:
  - C++: simulation core (used for efficiency & speed)
  - oTCL: simulation configuration (input topology, applications, ...)



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Exemplar Simulation Package 2

OPNET (http://www.opnet.com/)

- Popular commercial networking simulator
  - Free academic license (6monthly renewal, "OPNET lite")
- Packet-level discrete event simulator
- Impressive array of products, modules & customers
- Modeler
  - "the industry's leading environment for network modeling & simulation"
    - Object oriented approach
    - Graphical editors
    - Wide range of network types & technologies supported

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NS2 & OPNET

- Arguably 2 most popular packet-level networking simulators today
- For comparison, see

OPNET Modeler and Ns-2: Comparing the Accuracy Of Network Simulators for Packet-Level Analysis using a Network Testbed
Gilberto Flores Lucio et al.
3rd WEAS Int. Conf. on Simulation, Modelling and Optimization (ICOSMO 2003)
Vol. 2, pp. 700-707, 2003.

Choosing OPNET over NS-2
http://www.opnet.com/services/university/opnt_over_ns2.html

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Common Mistakes in Simulation Study

- **Inappropriate level of detail**
  - Level of detail discretionary → easy to have too much/little detail
- **Unverified model**
  - All complex programs prone to bugs → model may behave incorrectly
- **Invalid model**
  - Poor resemblance to reality
  - "Garbage in garbage out"
- **Insufficient simulation runs**
  - Each run is only sample path through model state space corresponding to particular sequence of random numbers
    →large number of runs mandatory for statistical validity
- **Too short simulation runs**
  - When model has large state space, model must be executed for long (simulated) time to ensure statistically valid sample path produced
- **Poor random-number generation**
  - May introduce correlation and/or bias into random variables which are used extensively in simulation

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Critique of Simulation Studies

On Credibility of Simulation Studies of Telecommunication Networks
K. Pawlikowski et al.
IEEE Communications Magazine
Vol. 40(1), pp.132-139, January 2002

- Over-reliance on simulation in systems research
- Widespread misuse & misunderstanding of simulation
- Simulation ≠ Programming
- Most simulation results poorly documented & not reproducible
- 2 pre-requisites of "credible simulation study"
  - Use of appropriate pseudo-random number generators of independent uniformly distributed numbers
  - Appropriate statistical analysis of simulation output data

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Simulation Modelling of the Grid

- Note that consequences of common simulation study mistakes more severe when considering the Grid
  - Much larger networks
  - Much bigger flows
  - Greater bit-rates
  - Much more complex interactions

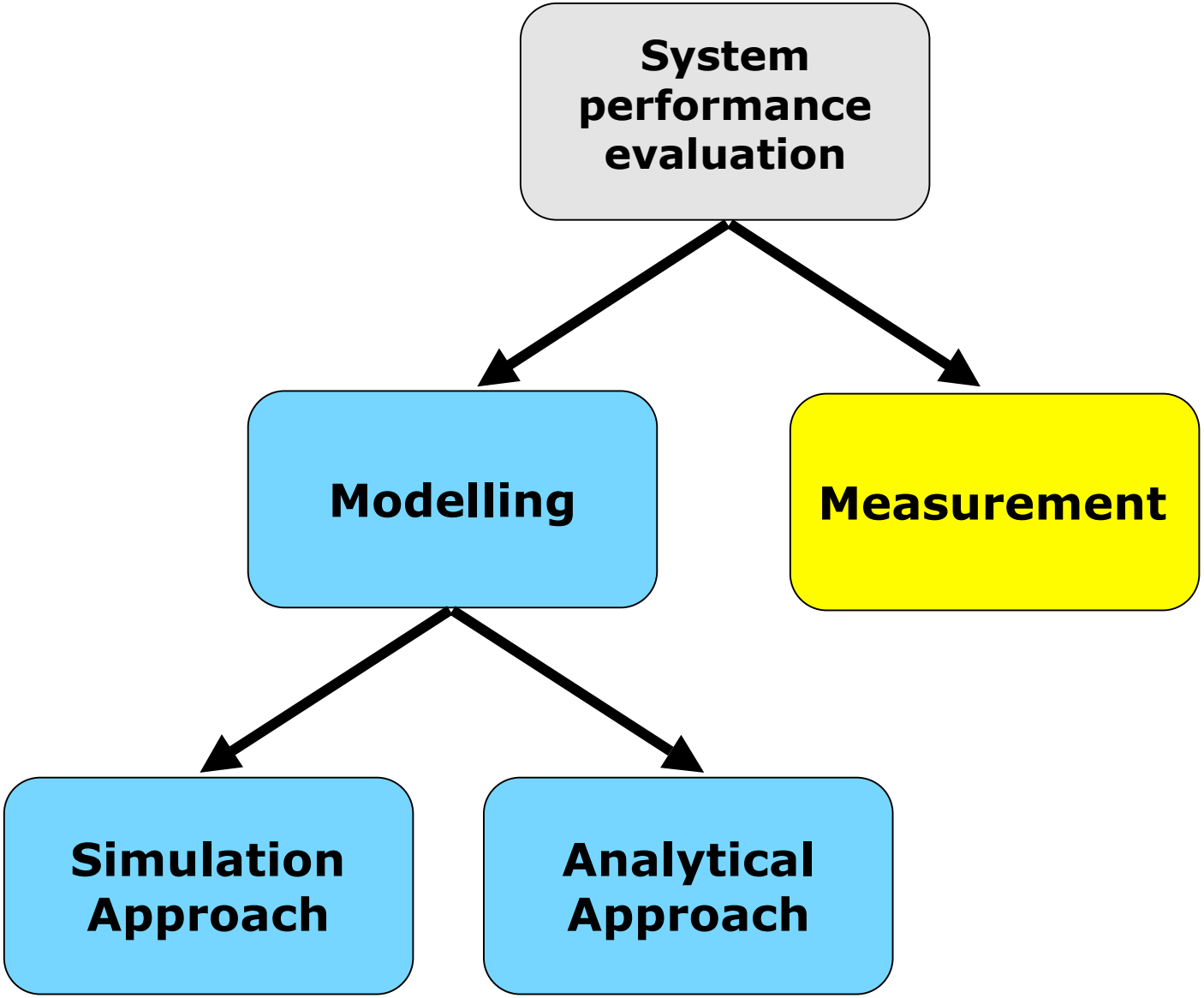
2 sentence summary

Difficult to conduct excellent simulation modelling of "traditional" networking systems

Even ***more*** difficult to conduct excellent simulation modelling of the Grid

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System Performance Evaluation Choices



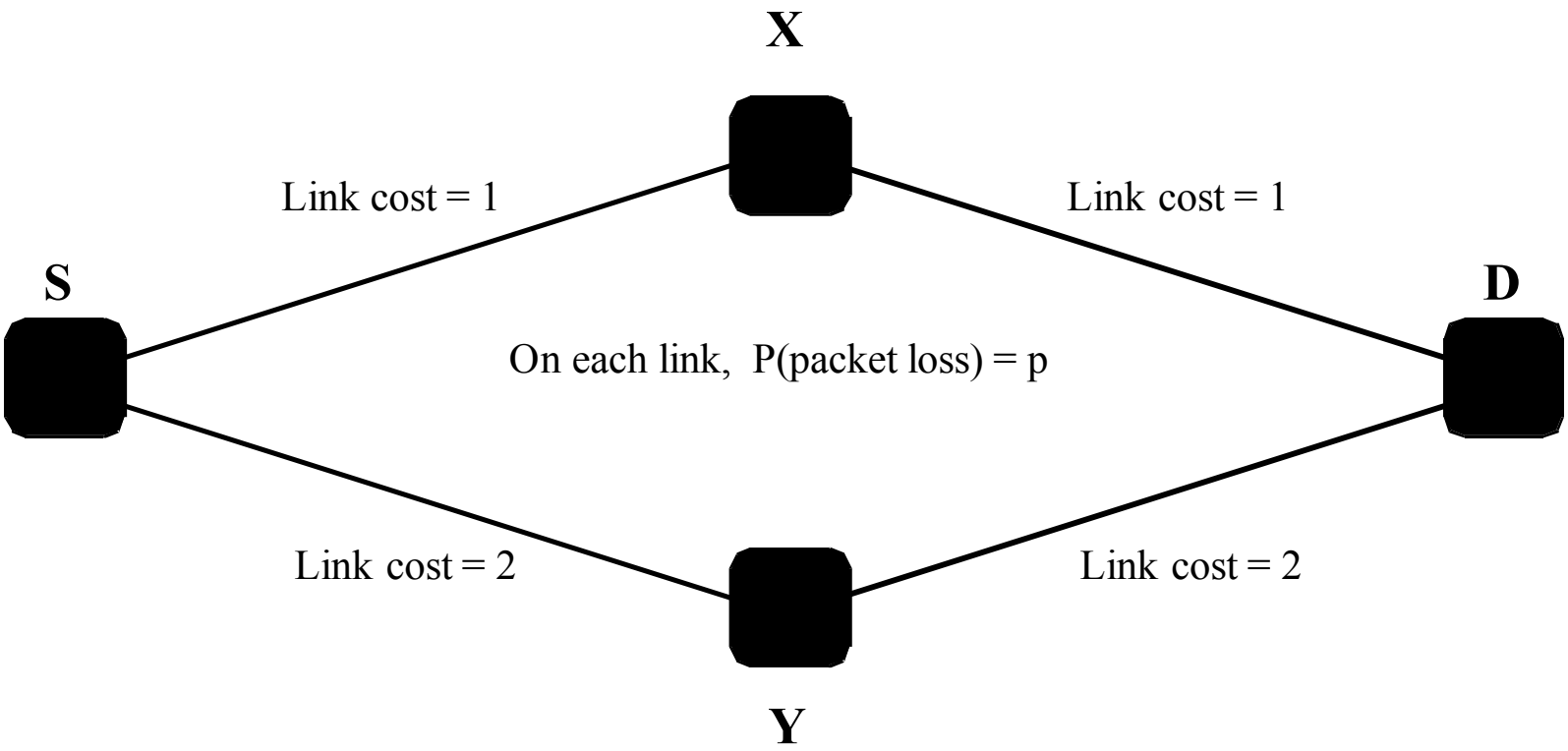
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Analytical Modelling

- Stochastic nature of communication systems
- Hence analytical modelling is
  - Typically complex
  - Heavily dependent on statistics
    - Good understanding of statistics pivotal(!)
  - Conducted by "mapping" system to one of several "classical" analytical models
    - i.e. not starting from scratch and proving all foundational mathematics & statistics but rather build upon existing proven results
- As expected, lots of flavours of analytical models exist
- Best to consider a simple case study…

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Analytical Modelling: Case Study

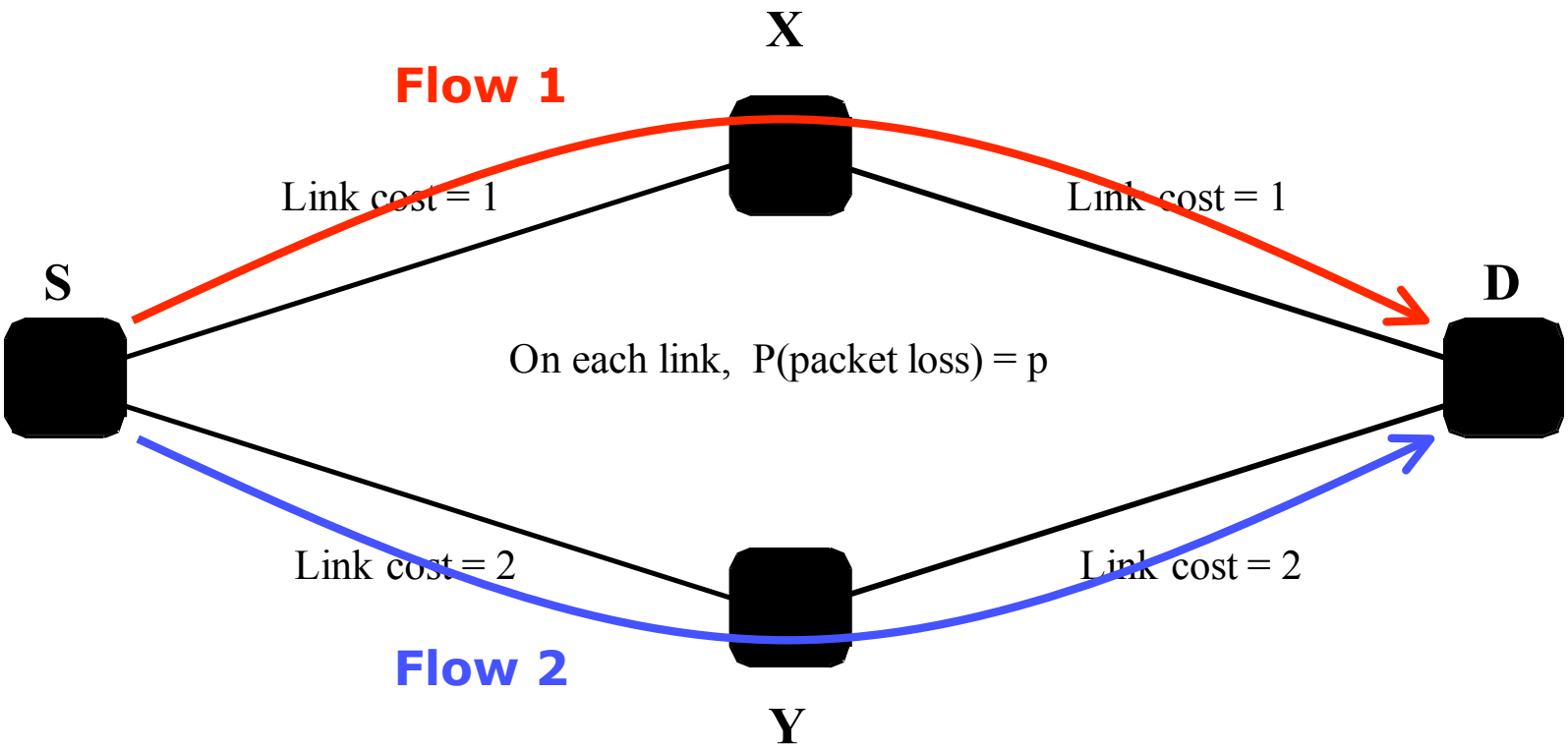


S wishes to set up two consecutive connections D

Only one flow can accommodated per link…

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Analytical Modelling: Case Study

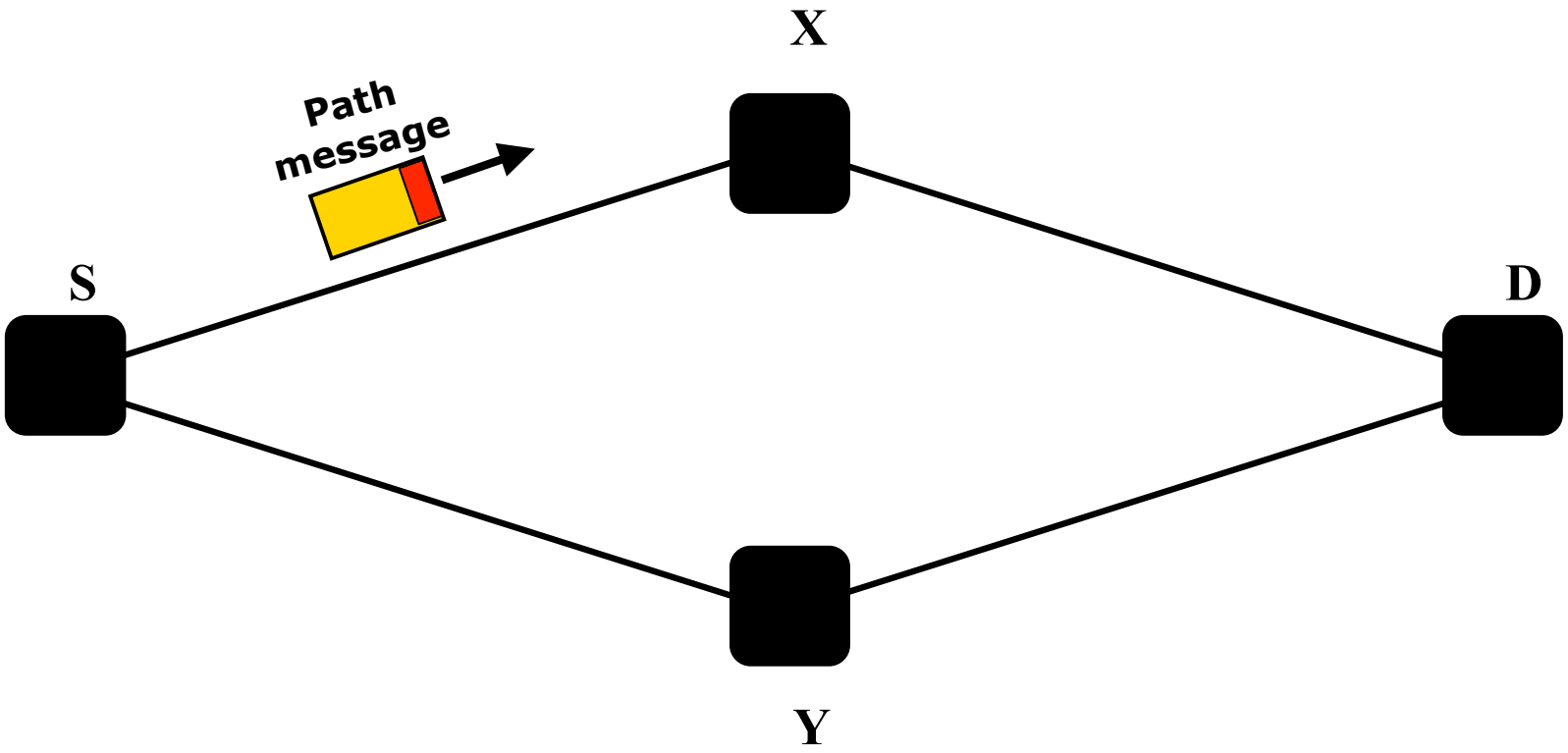


Ideal scenario

Dependent upon receipt of appropriate signalling and routing messages BUT packets may be lost!!

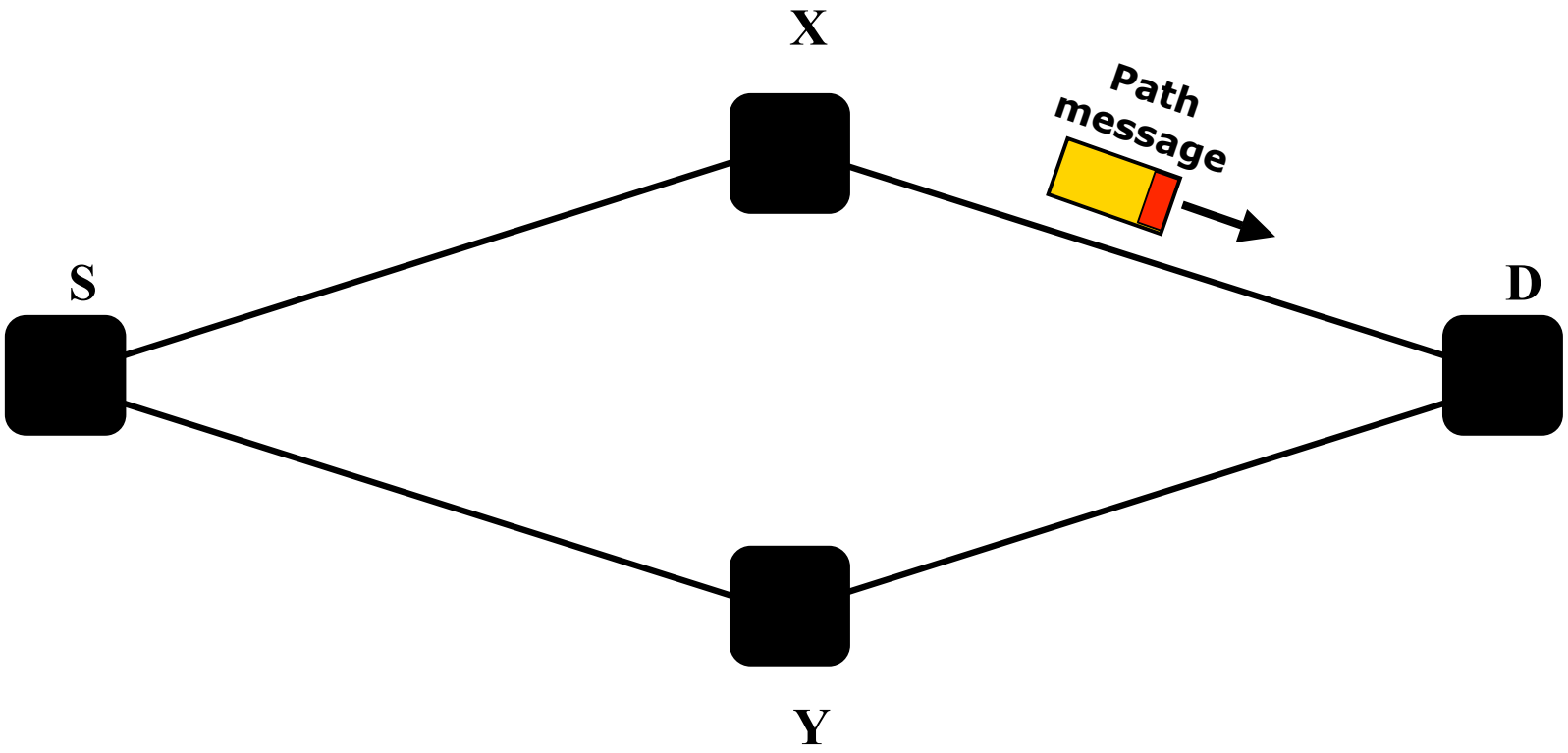
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Analytical Modelling: Case Study



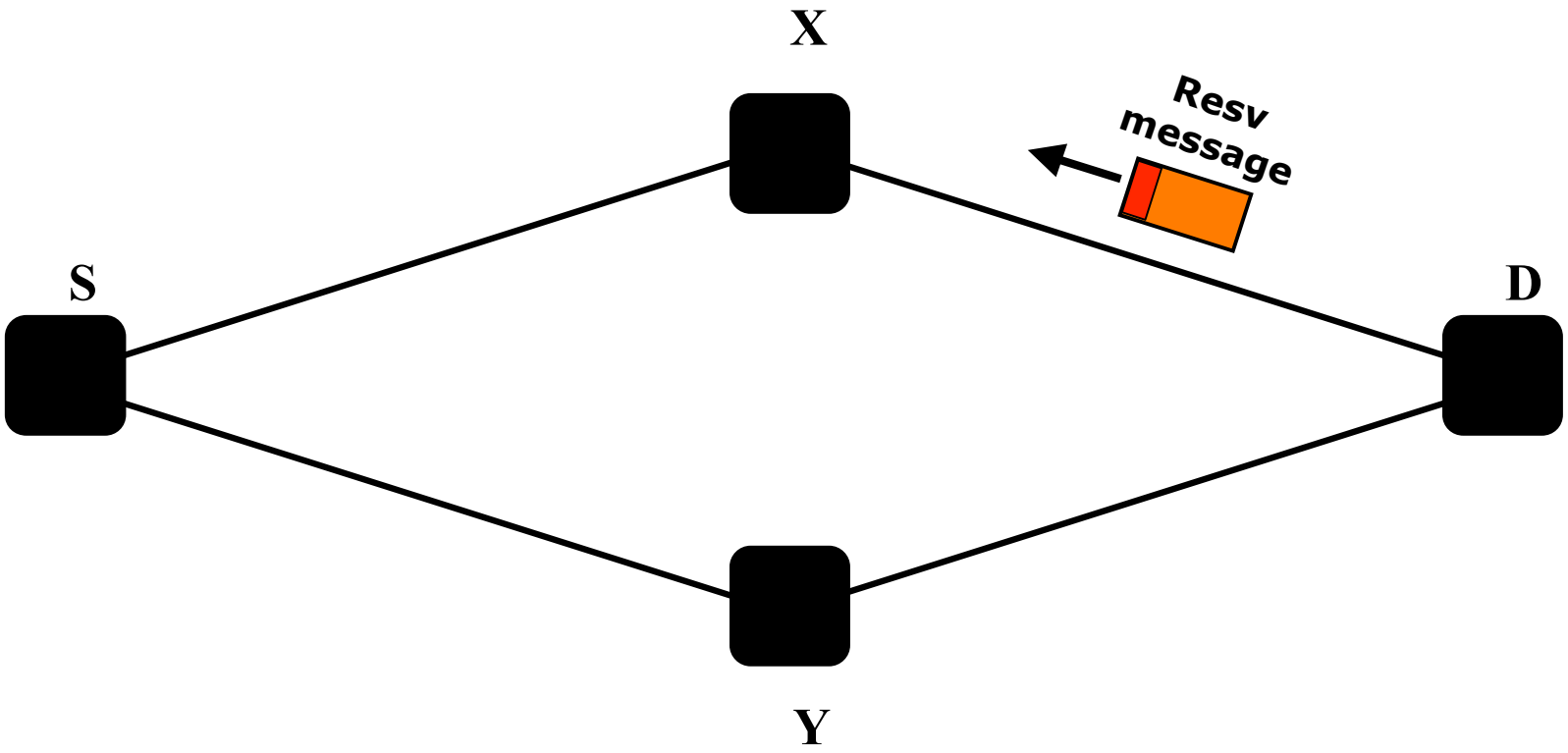
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Analytical Modelling: Case Study



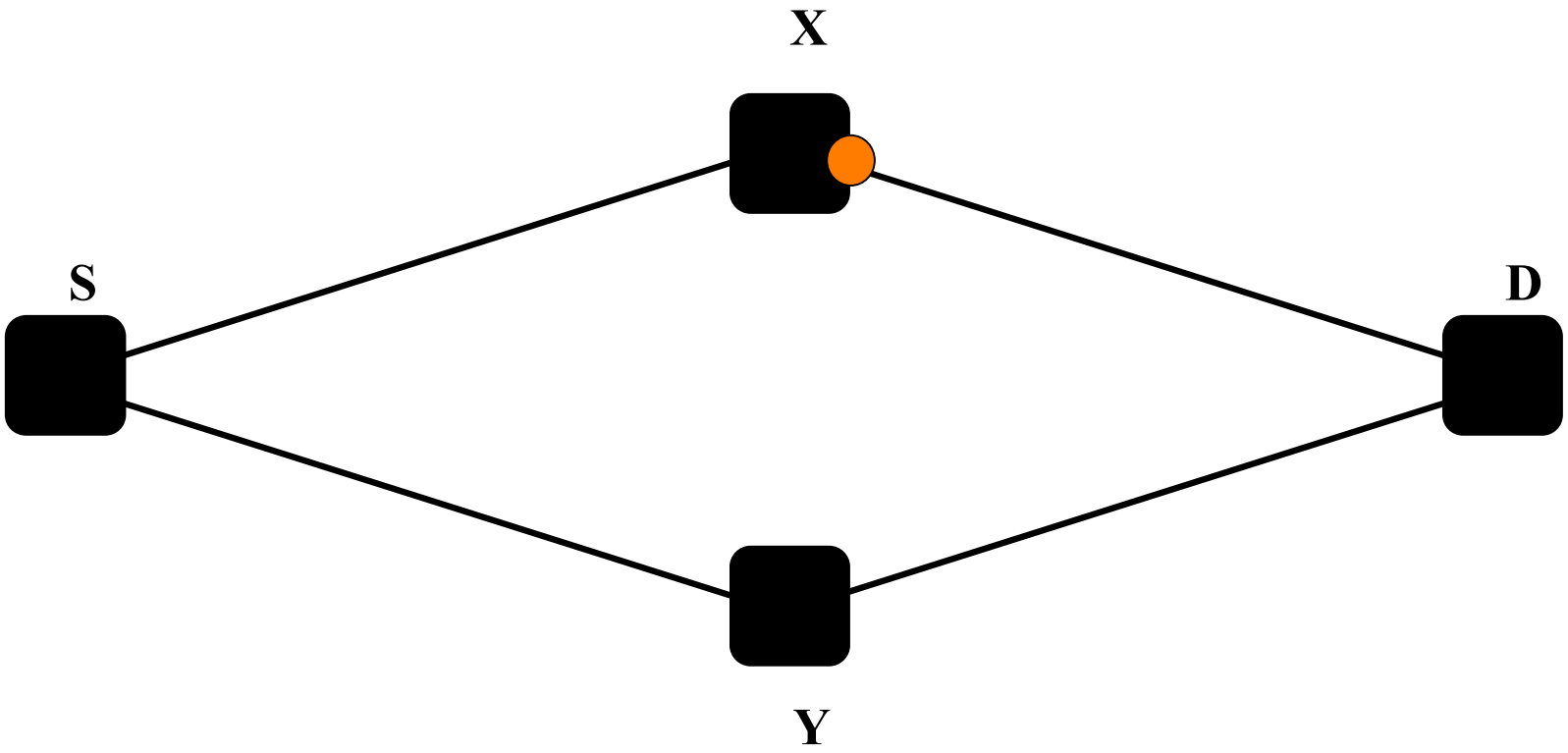
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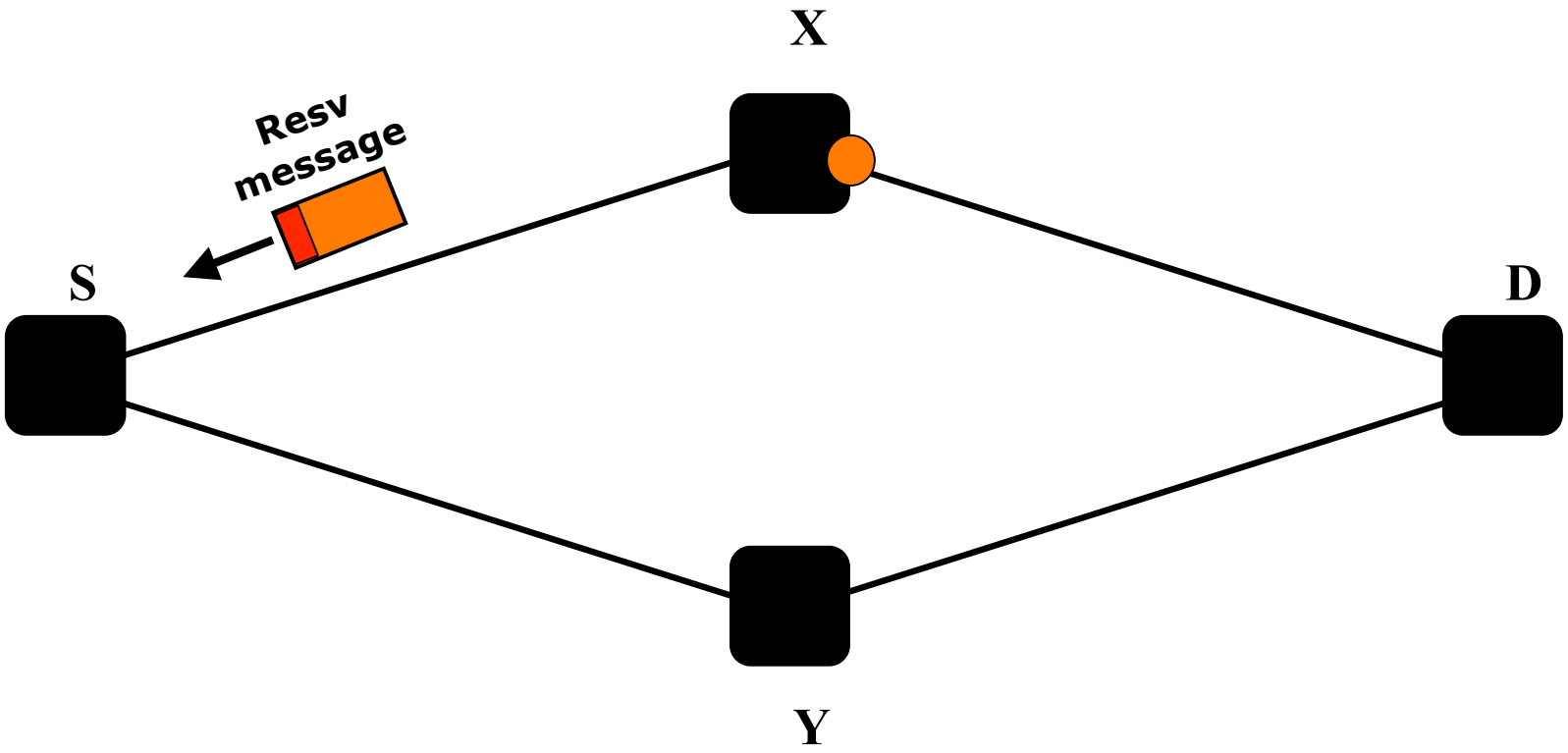
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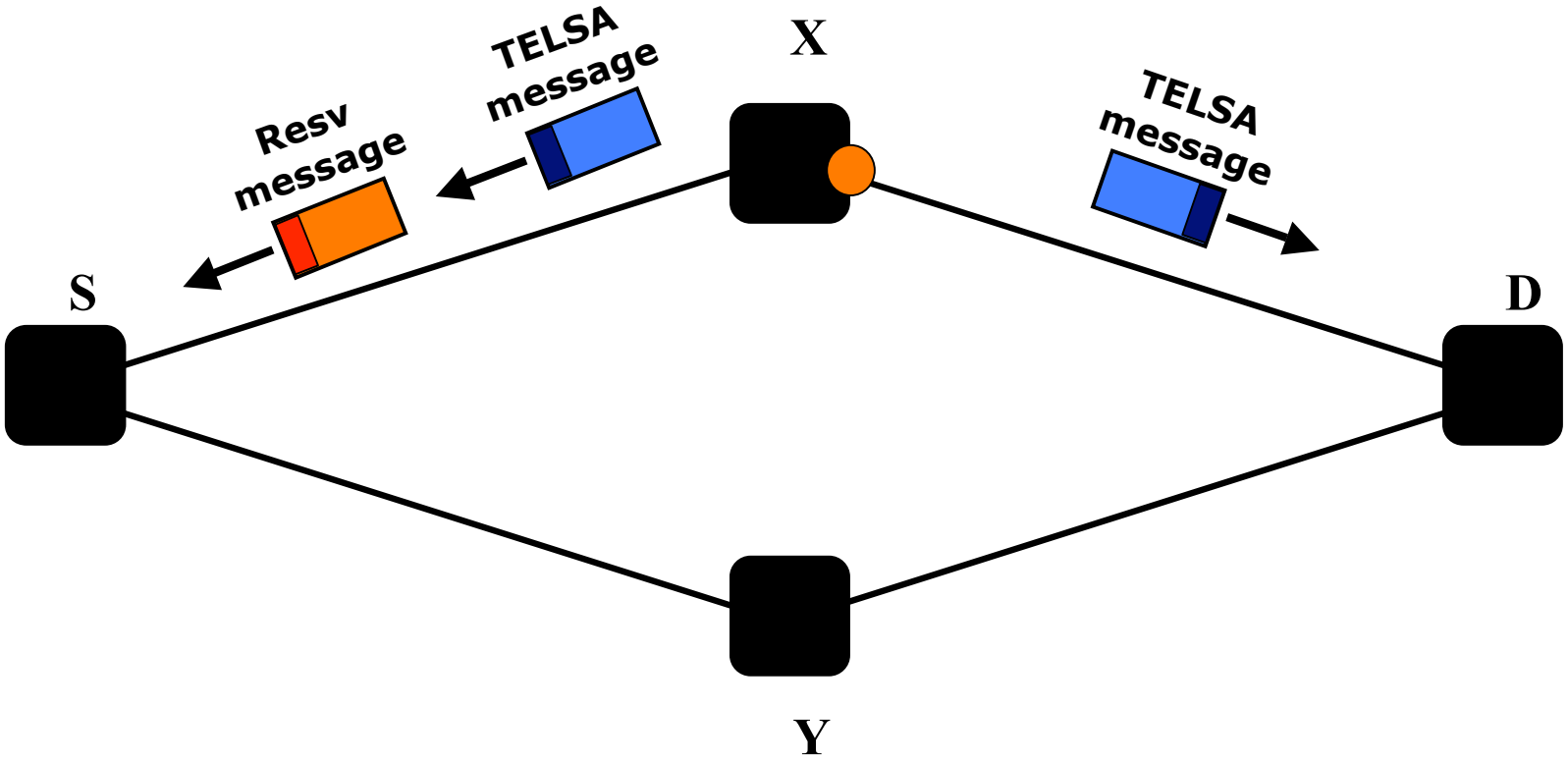
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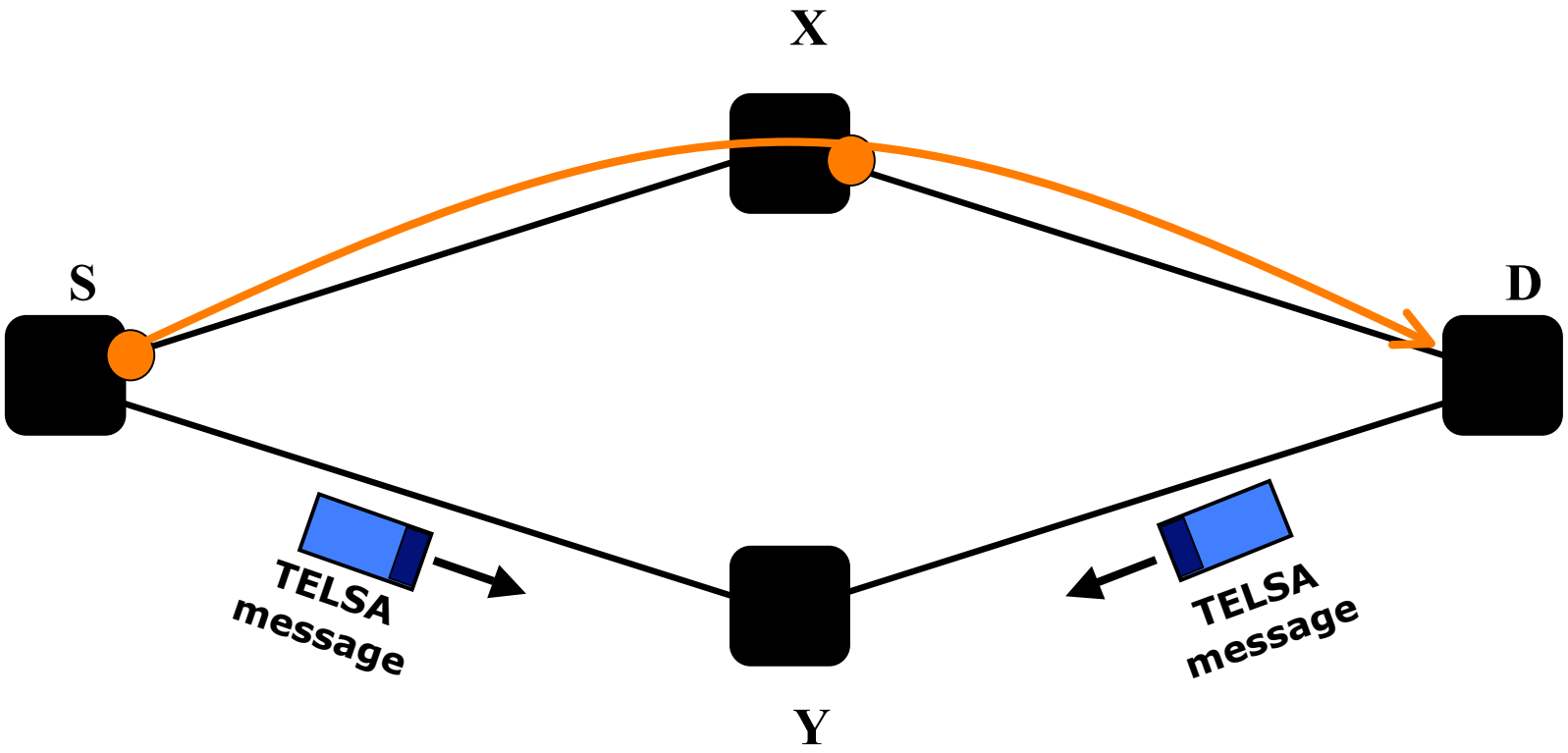
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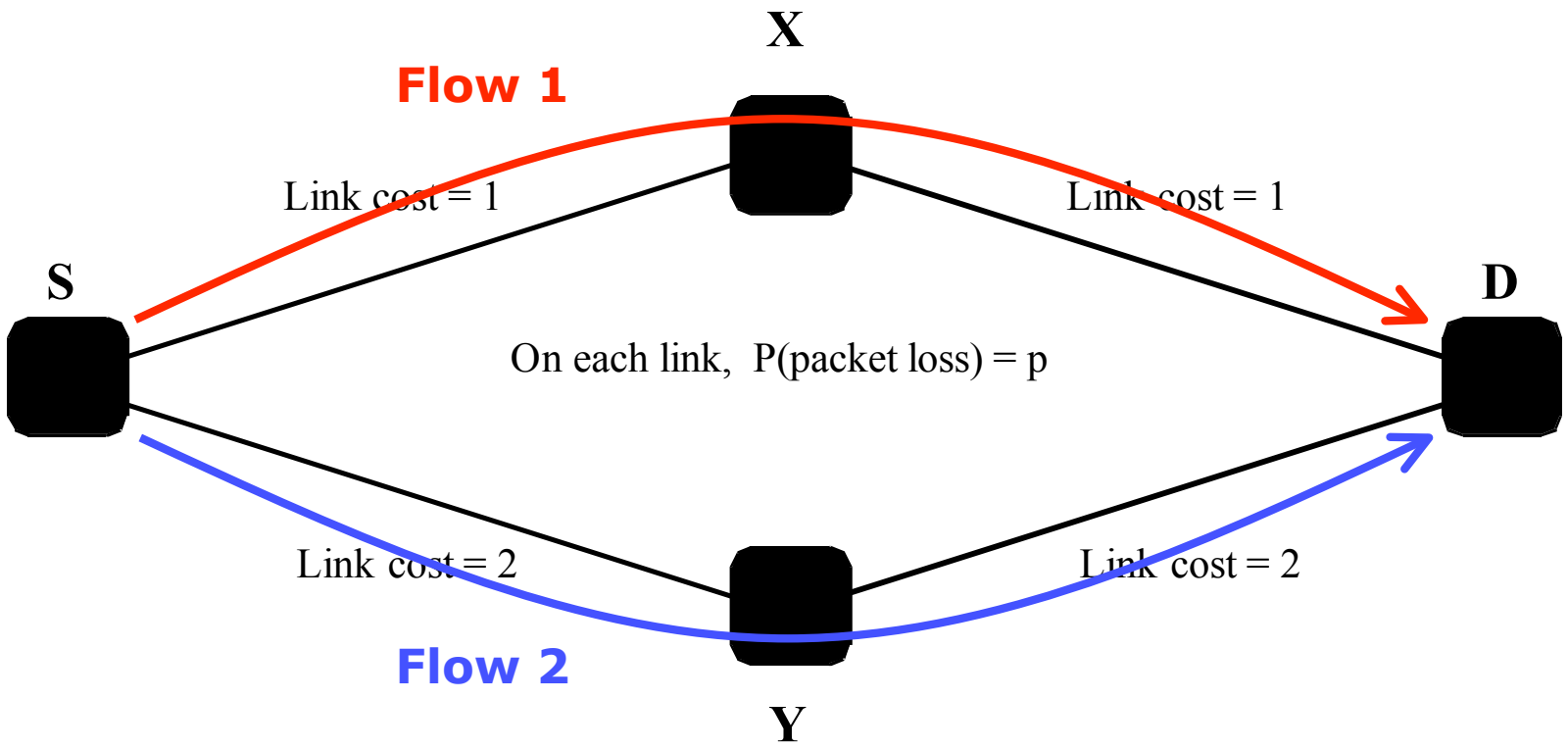
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Analytical Modelling: Case Study



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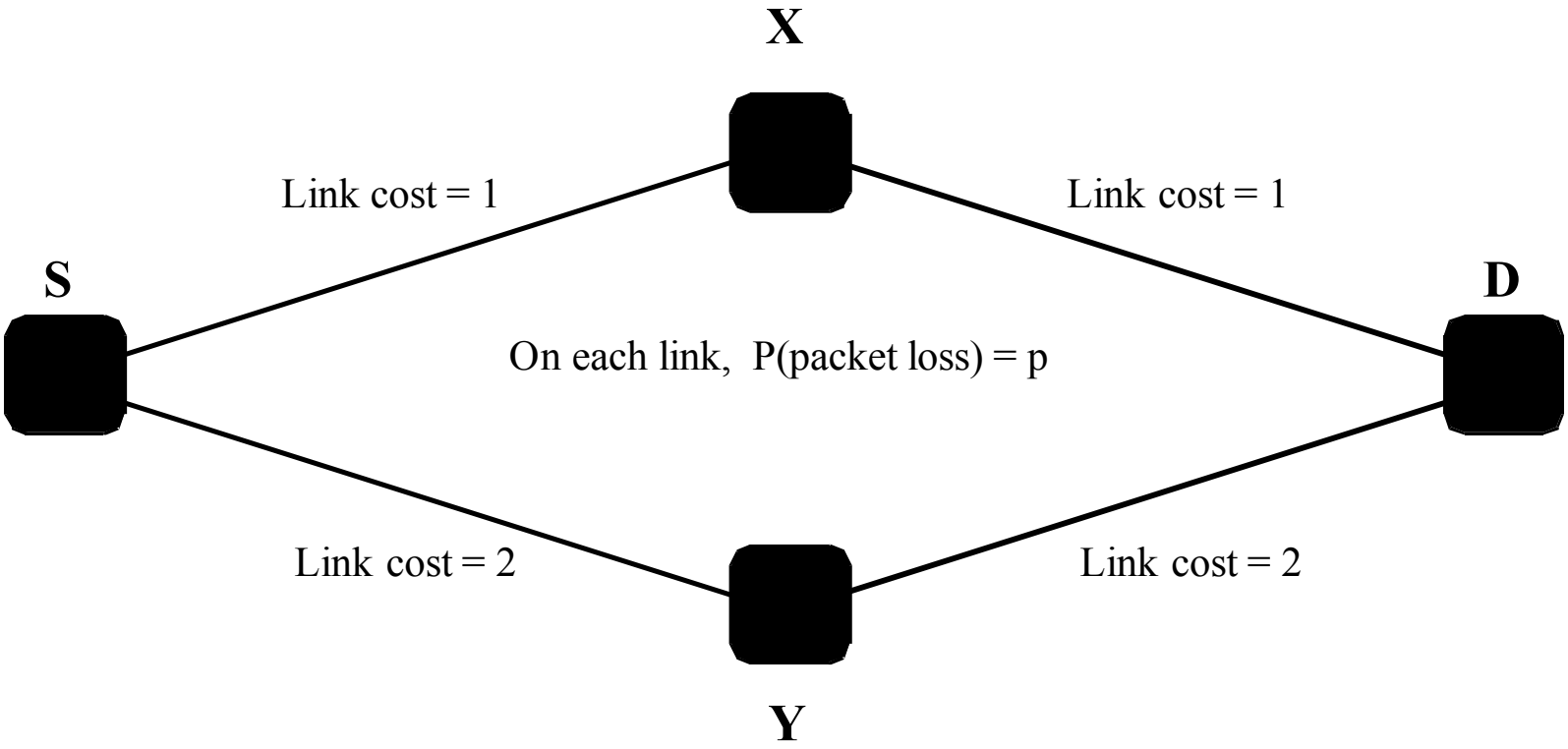


Ideal scenario

Dependent upon receipt of appropriate signalling and routing messages BUT packets may be lost!!

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Using Modelling to Evaluate Performance



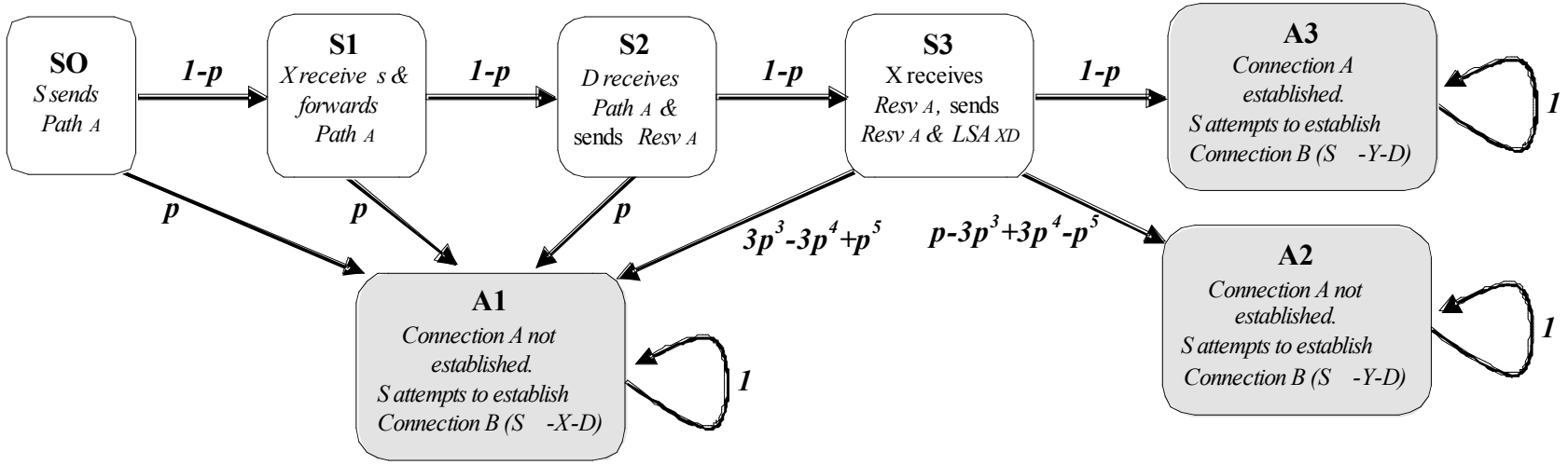
Given a packet loss probability of *p*

What is the probability of both flows being correctly established?

What is the probability of only one flow being correctly established?

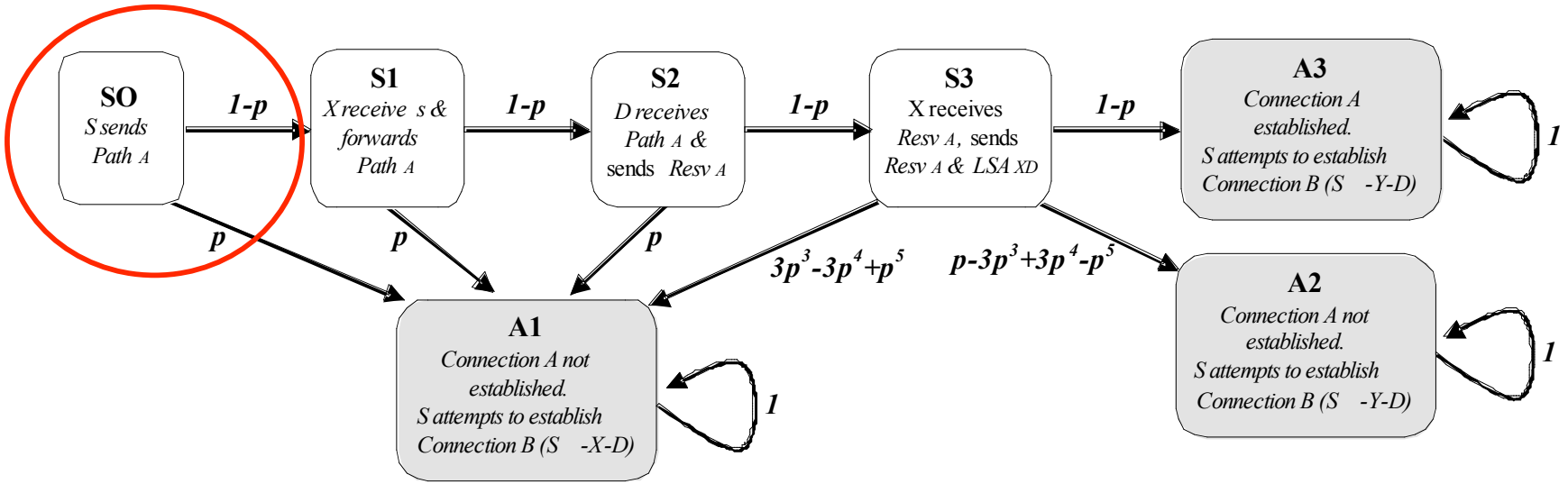
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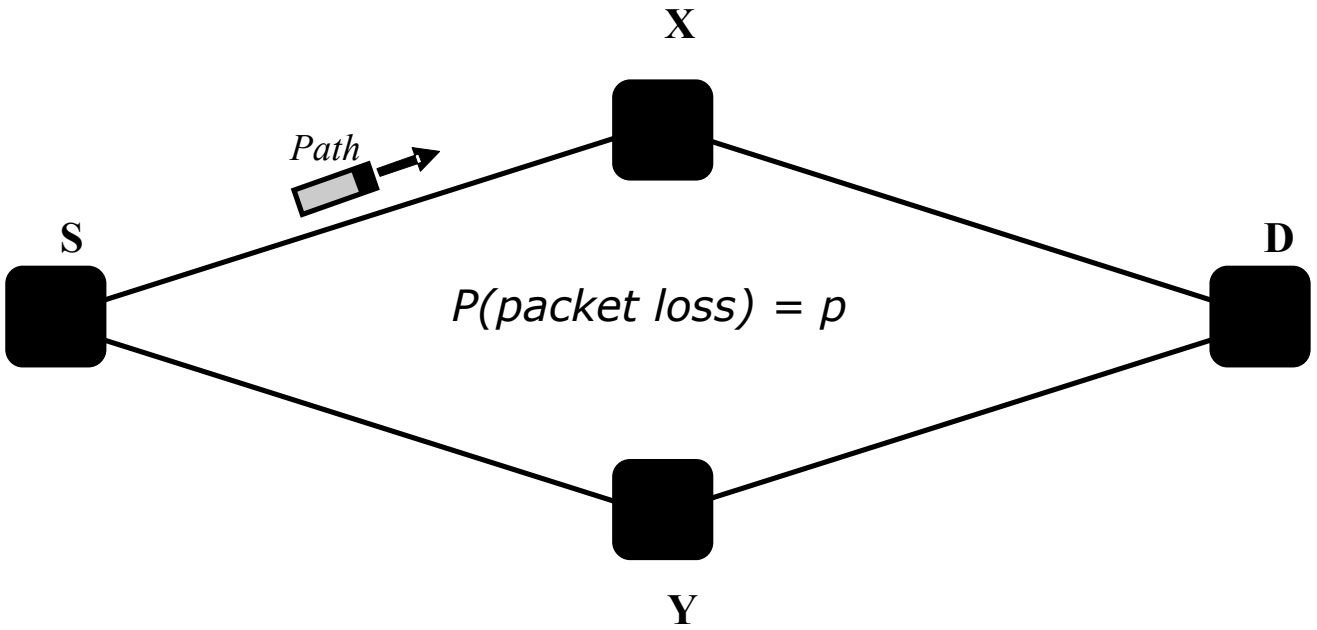
State Transition Diagram: No Retransmission



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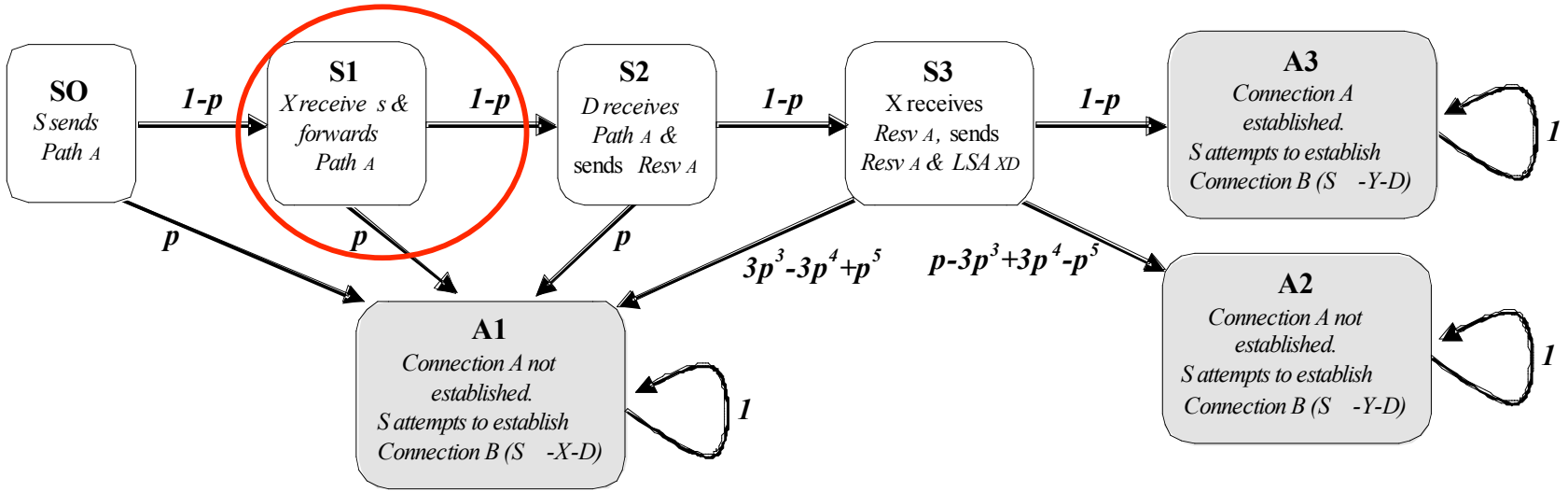
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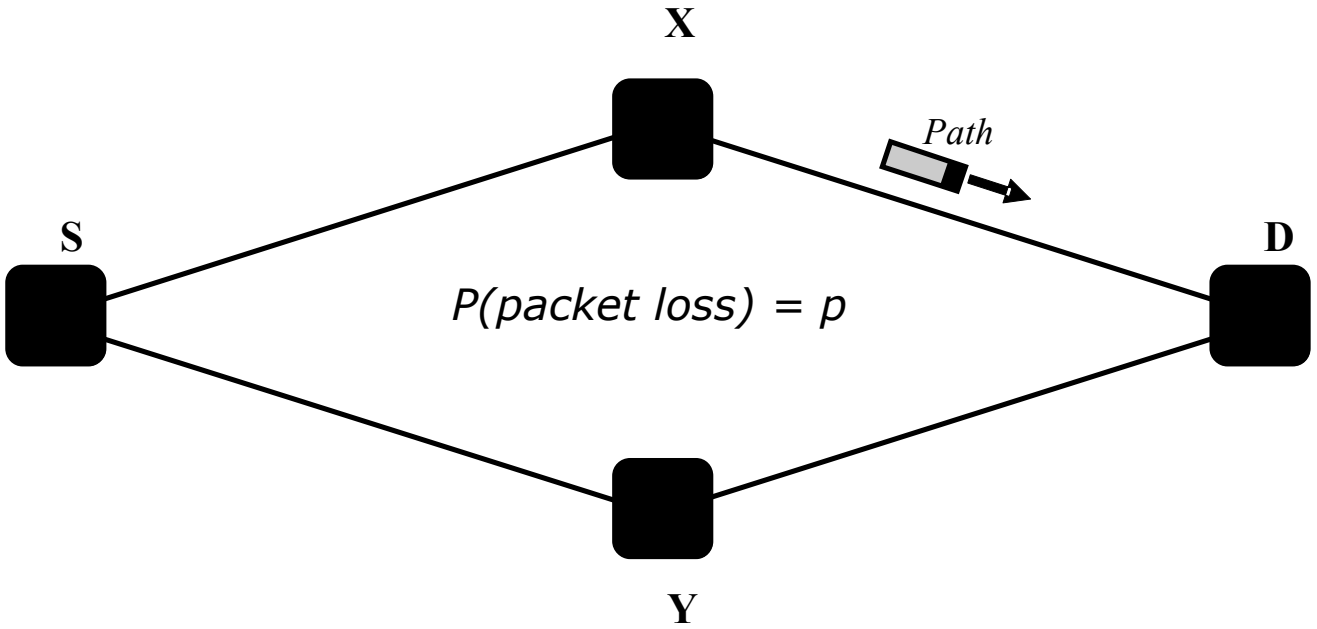




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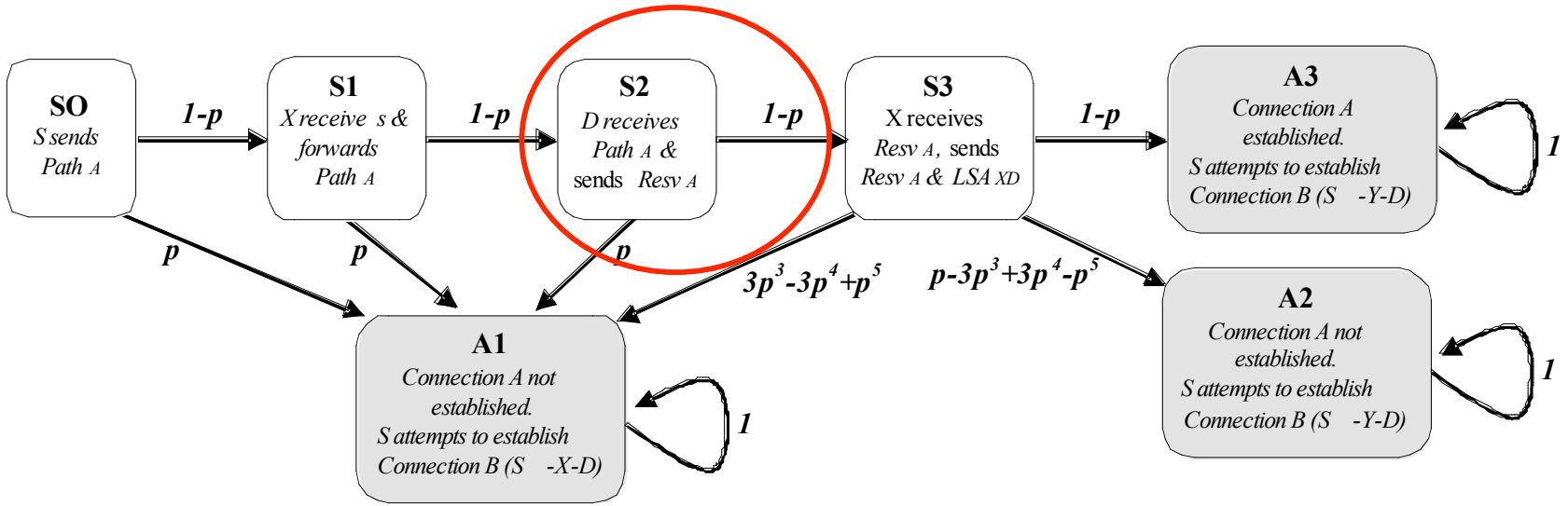
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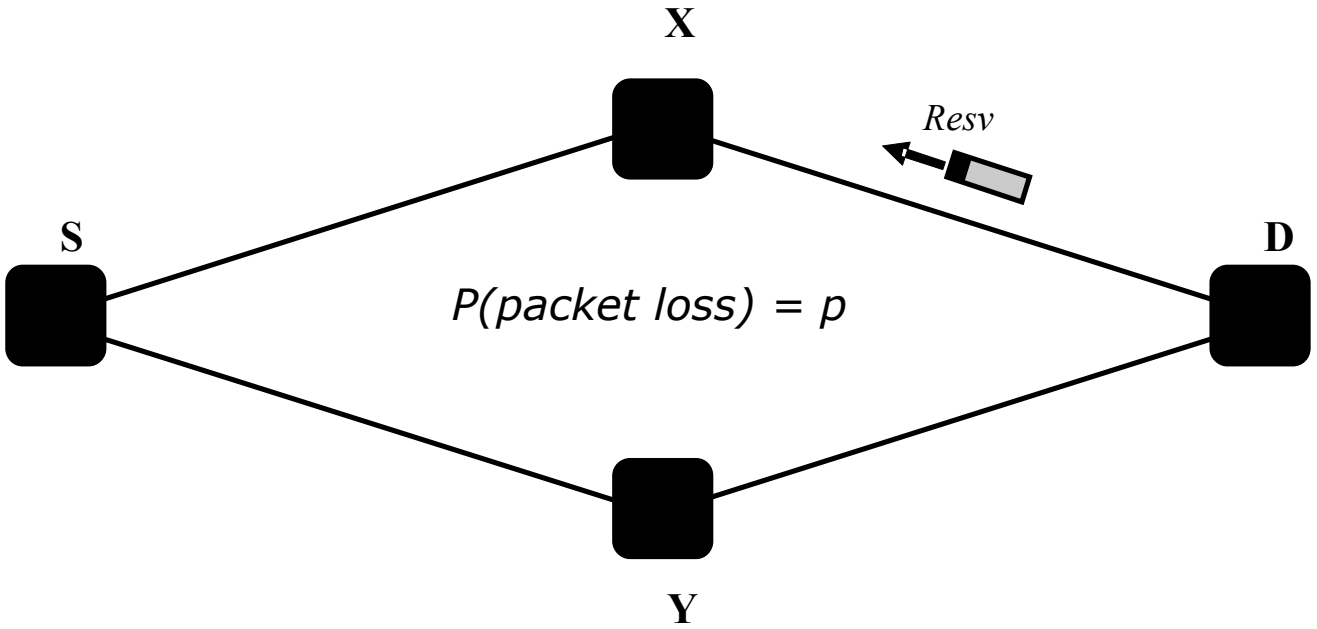




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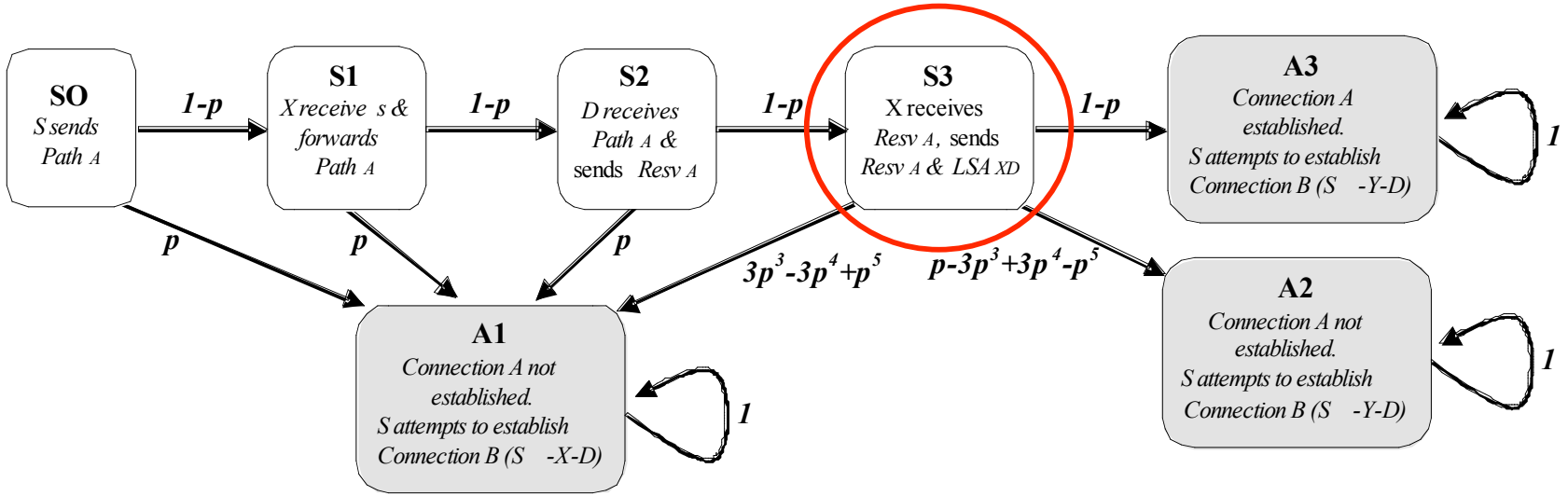
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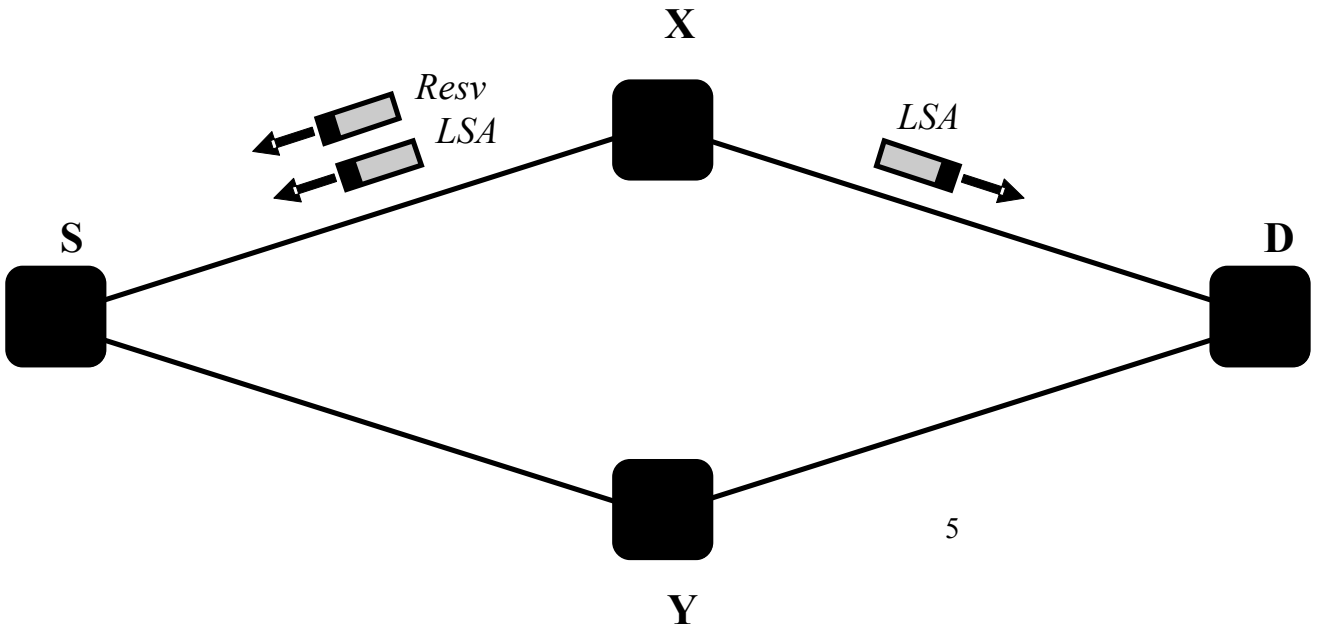




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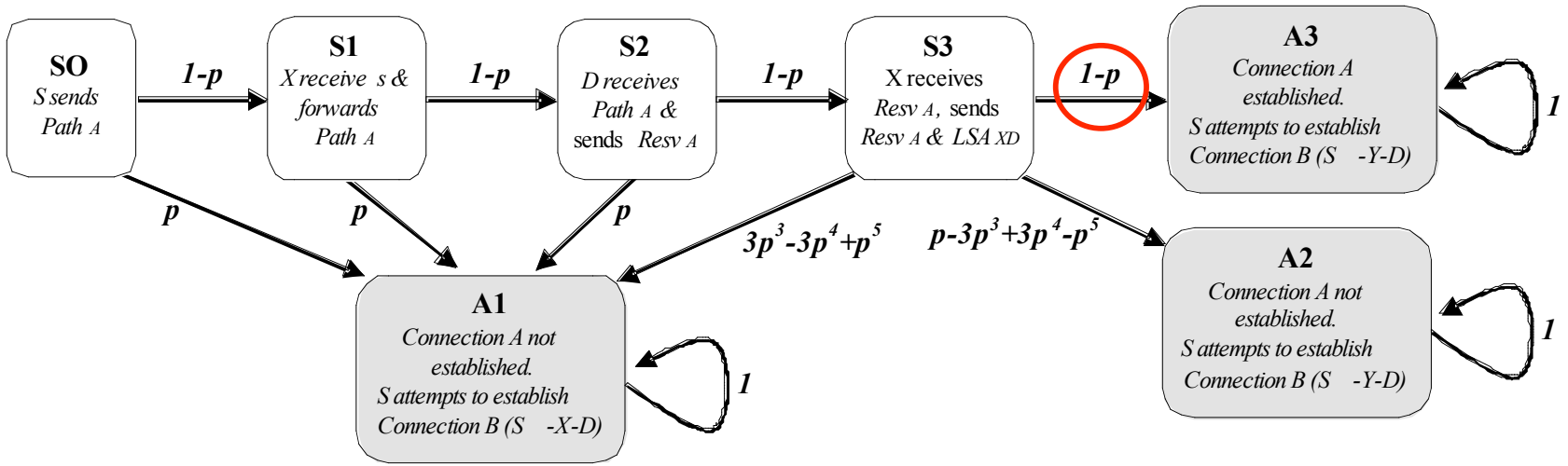
State Transition Diagram: No Retransmission

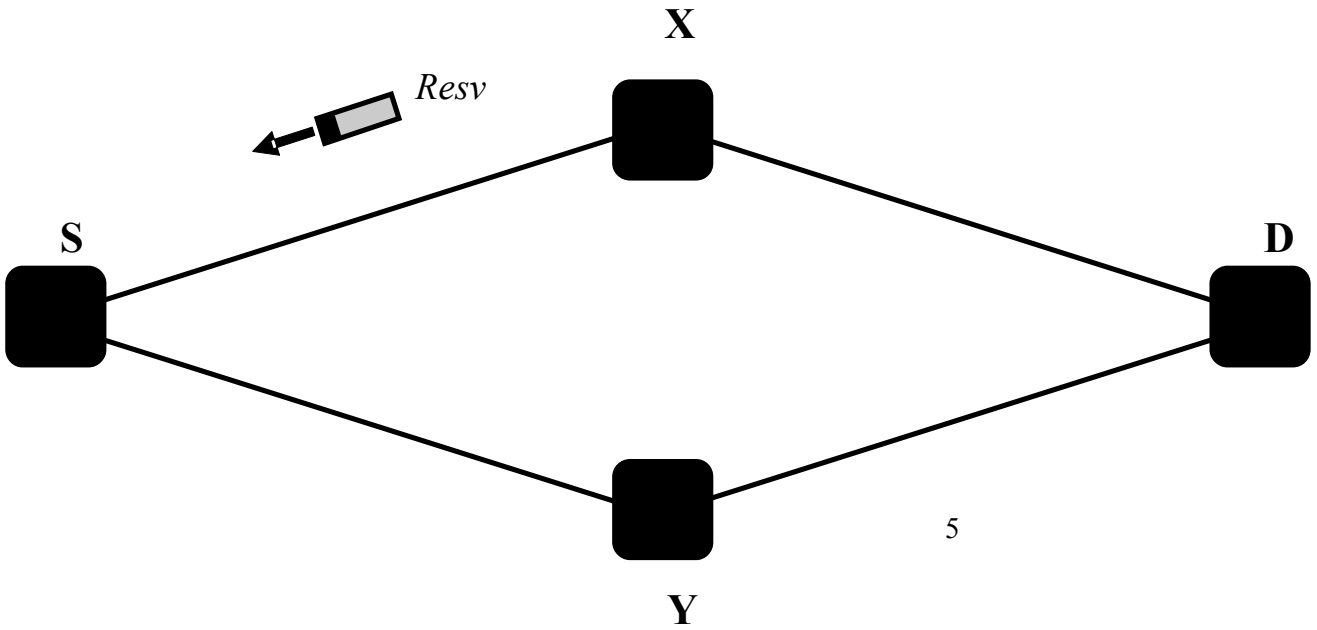




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State Transition Diagram: No Retransmission

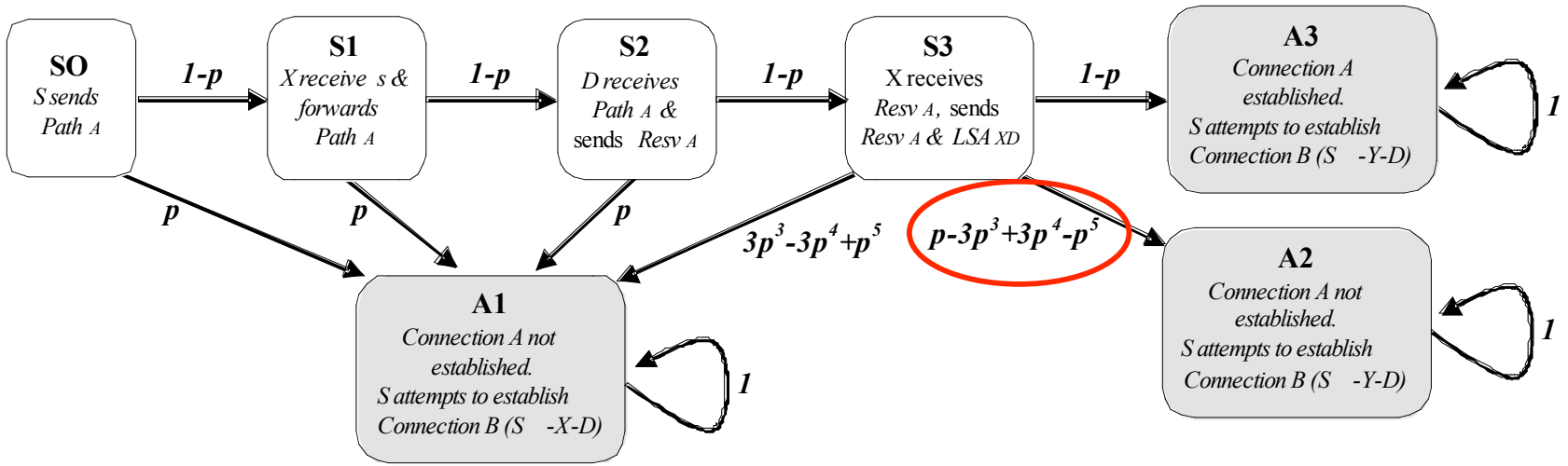


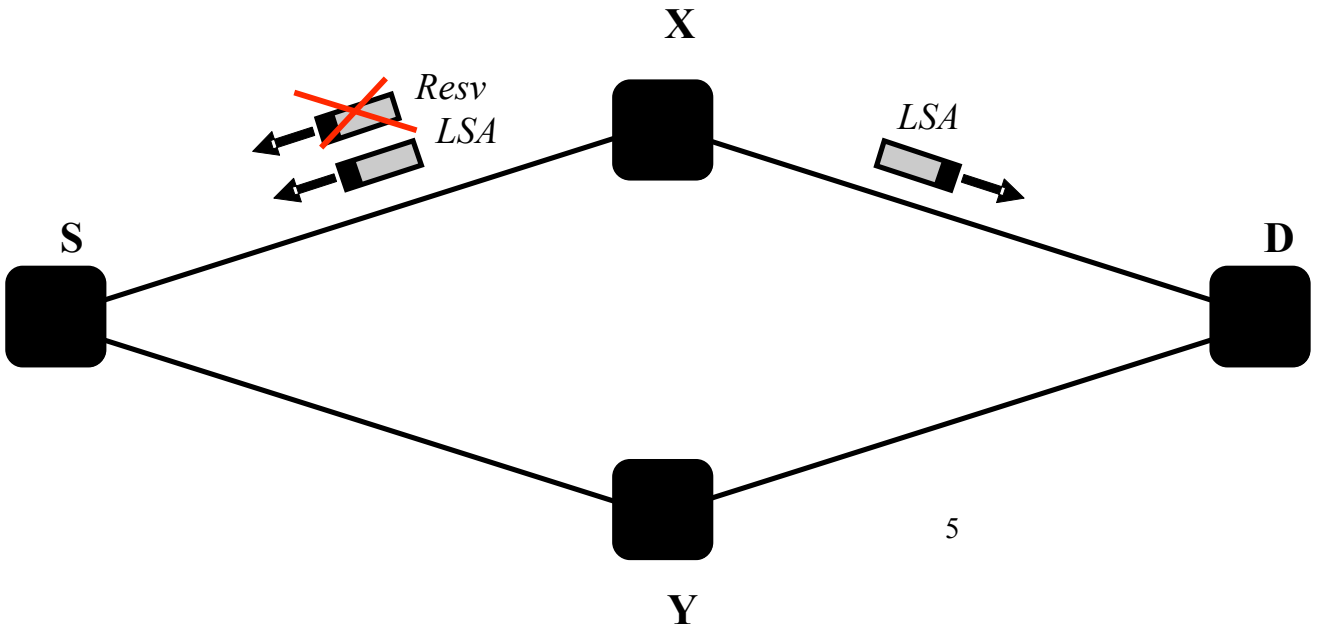


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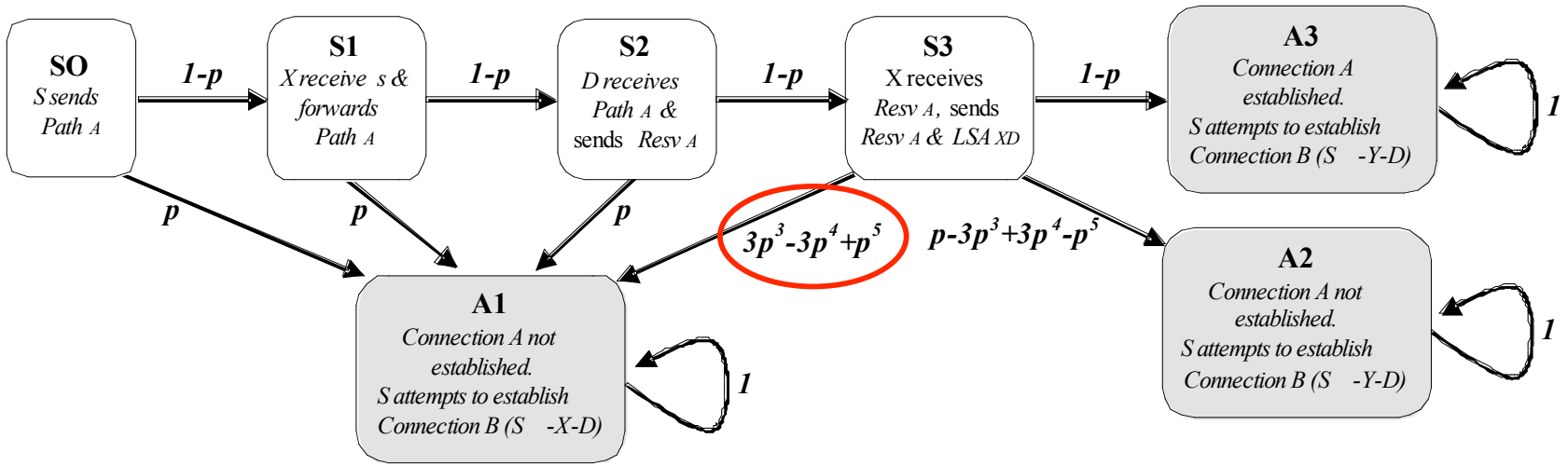
State Transition Diagram: No Retransmission

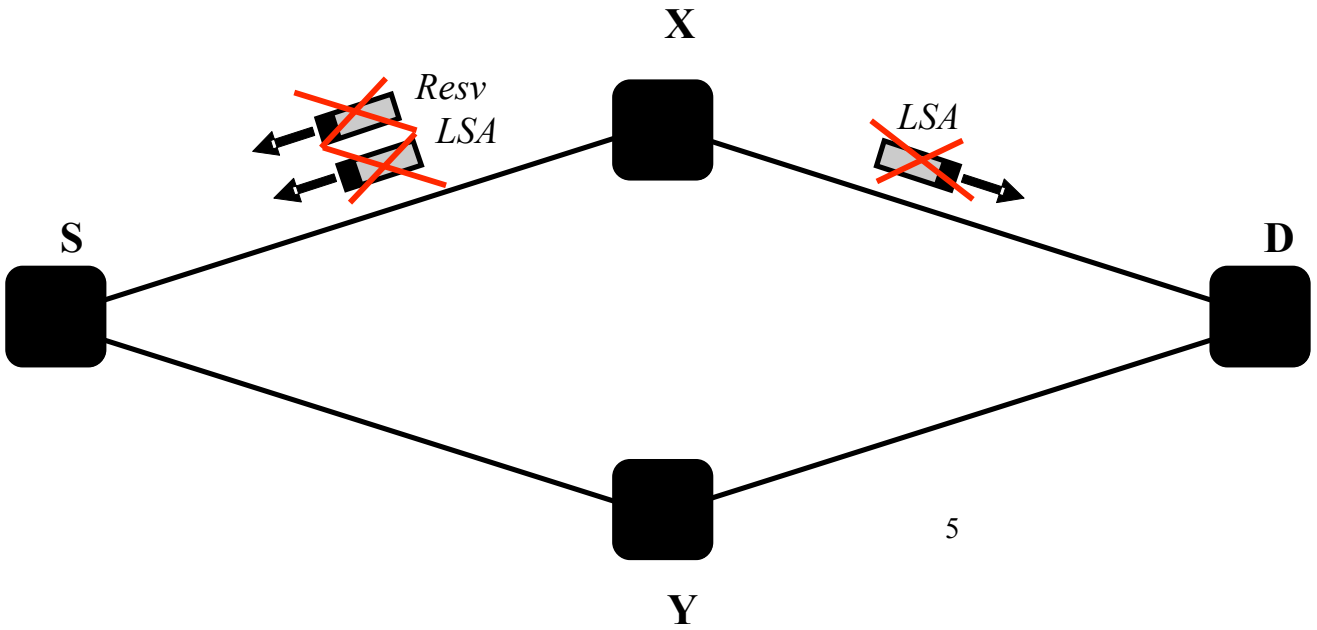




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State Transition Diagram: No Retransmission





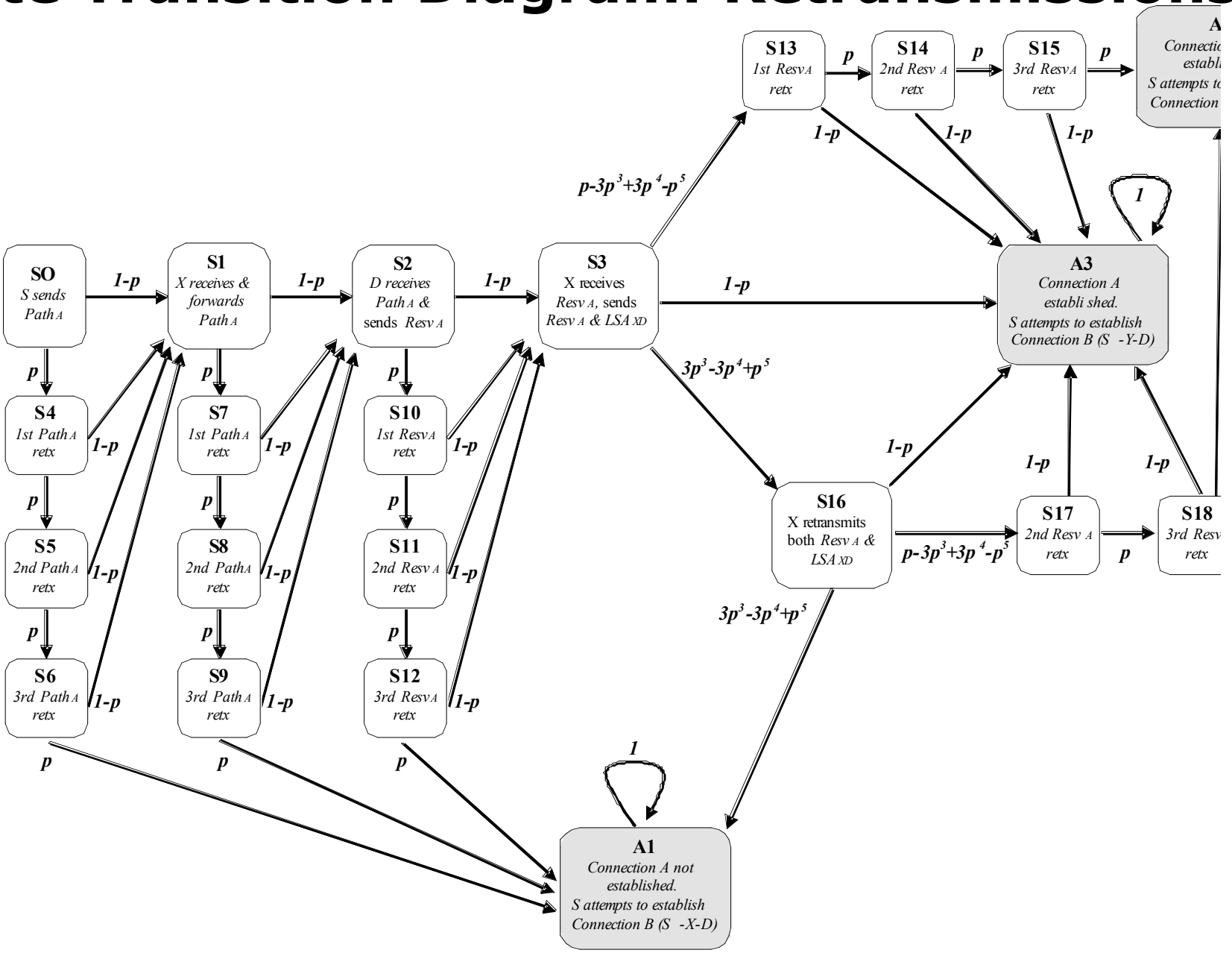
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Evaluating System Performance

- State transitions describe system behaviour
- Must "solve" to evaluate system performance
- Based on theory of absorbing Markov chains
  - Markov Chain
    - Special type of discrete state stochastic process
    - Probability distribution at time *t+1* depends only at state at *t* (and not state at *t-1, t-2,t-3, … 0*)
  - Absorbing State
    - A state from which there is zero probability of exiting
- Use known results of absorbing Markov chains to compute probability of absorption in particular absorbing state as function of p….
  - Write out state transition matrix (Table 1)
  - Isolate transitions between non-absorbing states (Q, Table II)
  - Isolate transitions between absorbing states (R, Table III)
  - Compute fundamental matrix, $F = (I-Q)^{-1}$
  - Compute absorption probabilities by calculating X = FR
    - Probabilities given in Equations 1 - 3

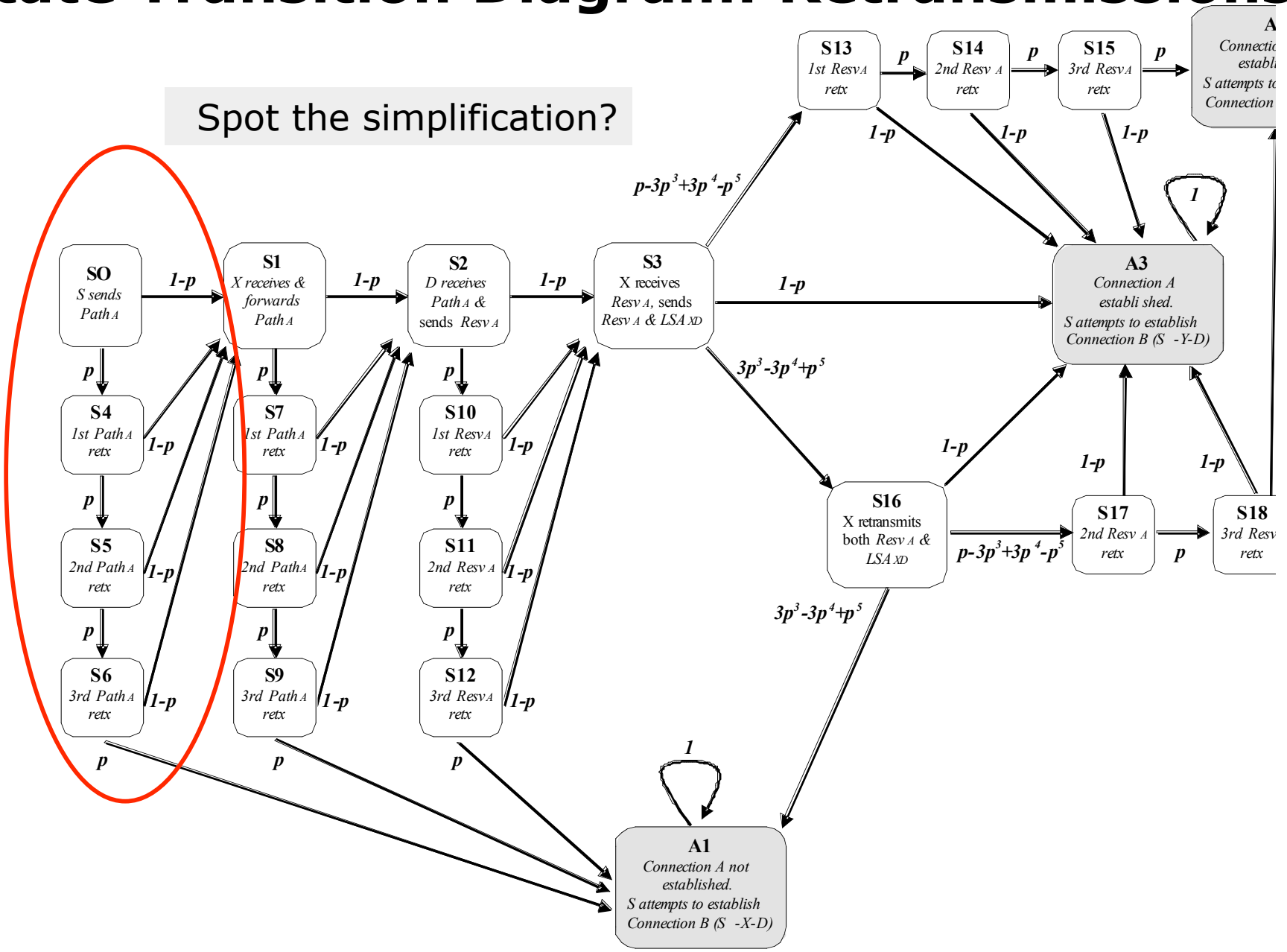
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State Transition Diagram: Retransmissions



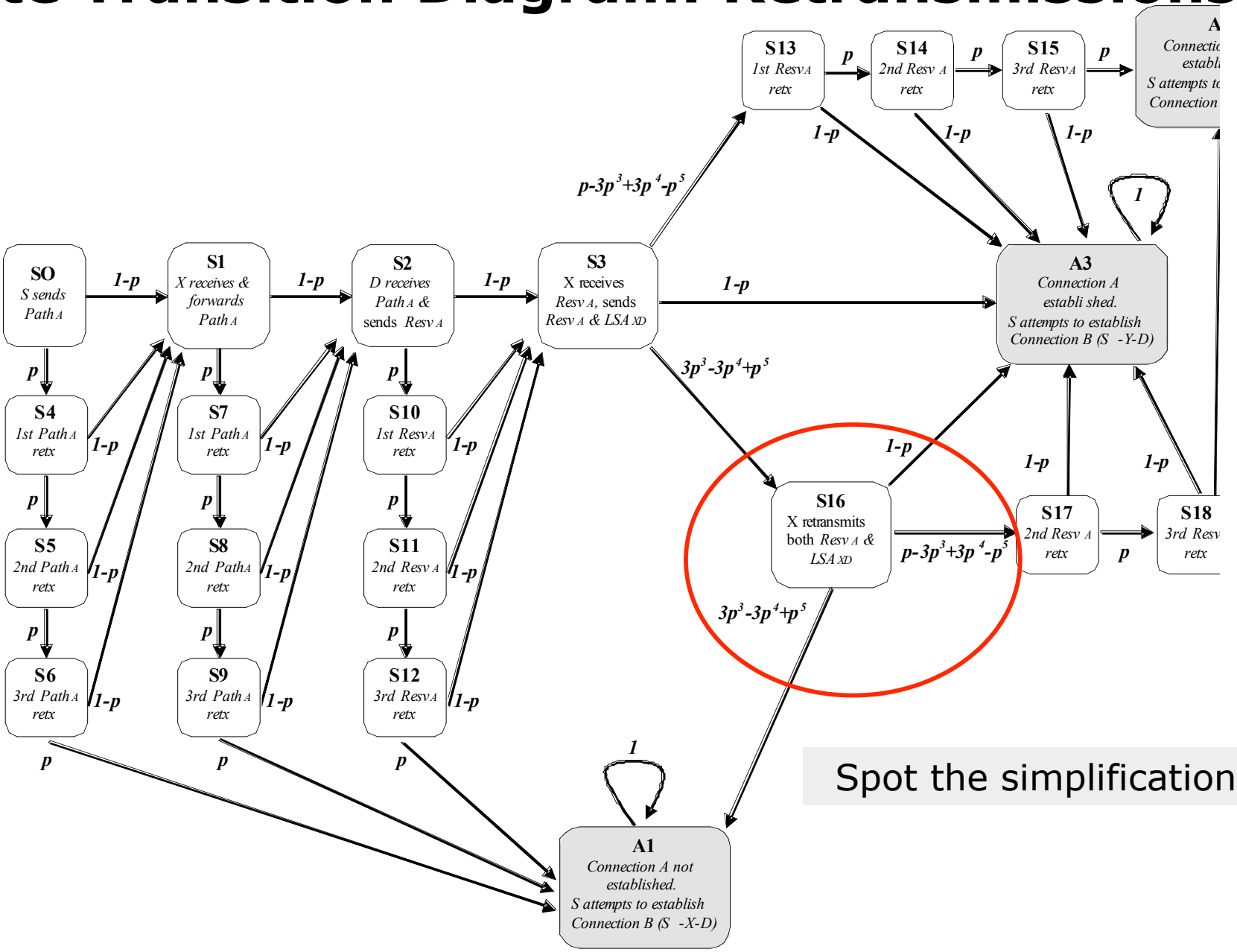
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State Transition Diagram: Retransmissions



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State Transition Diagram: Retransmissions



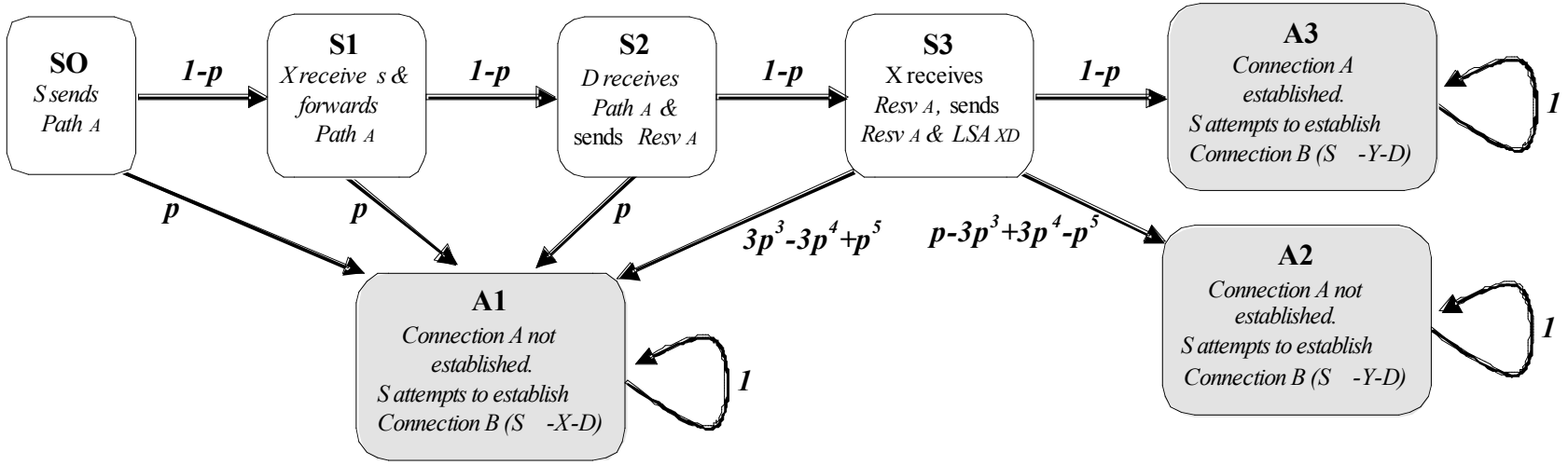
Spot the simplification?

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Simulation Modelling vs Analytical Modelling

Analytical Modelling

System performance evaluated by ***describing and analysing*** state space statistically



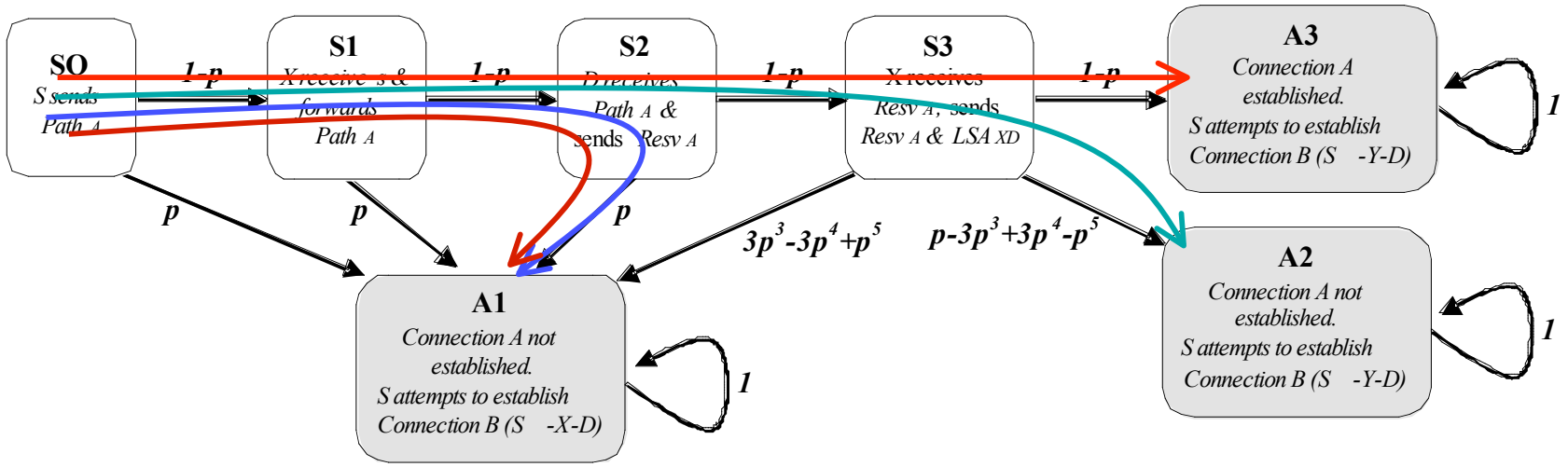
Solving equations gives insight into system performance

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Simulation Modelling vs Analytical Modelling

Simulation Modelling

System performance evaluated by ***sampling*** state space

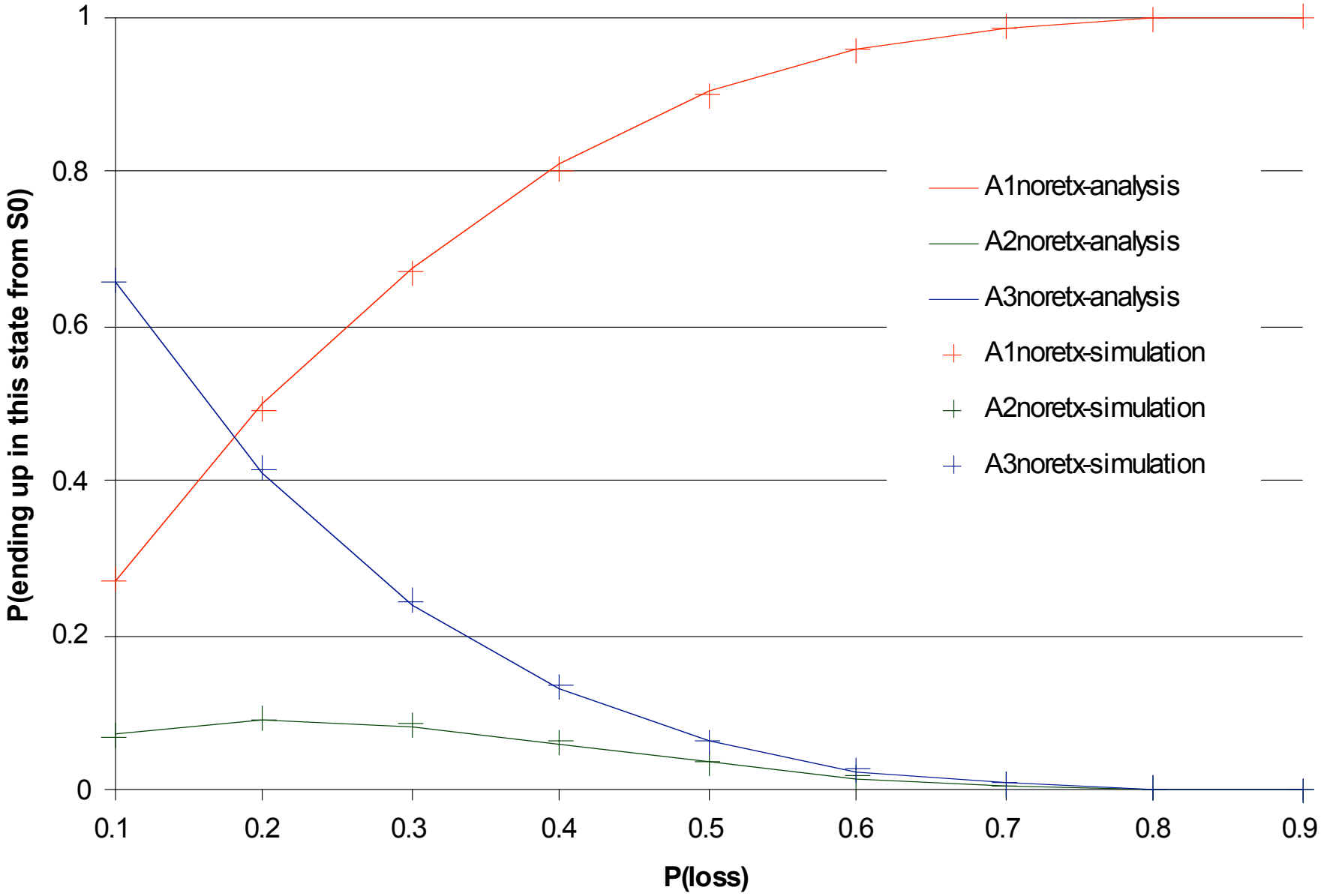


Each simulation run = sample of state space, hence critical to

- Take good & accurate samples (long simulation runs)
- Lots of samples (lots of simulation runs)
- Representative samples (good PRNG)

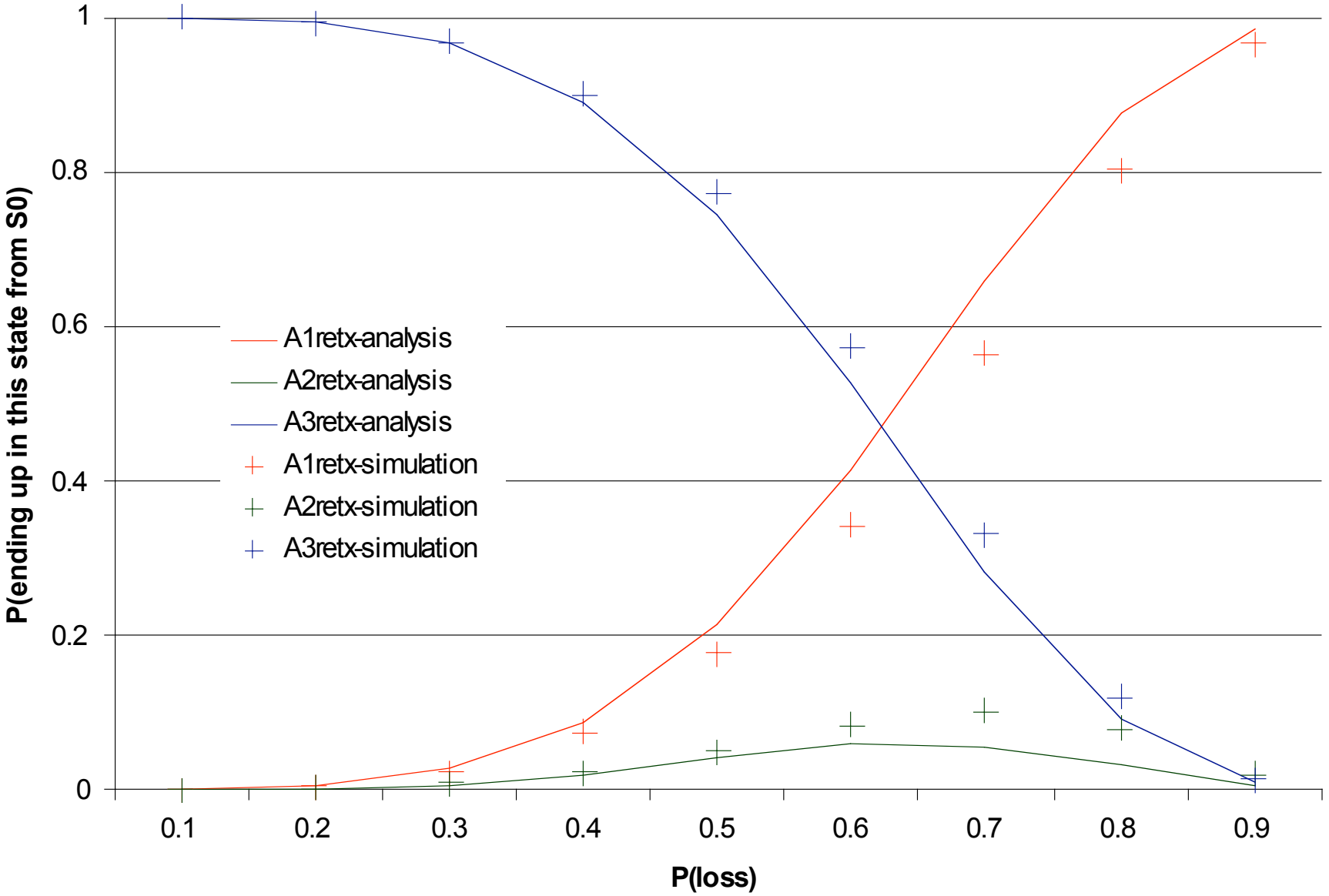
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Simulation Modelling vs Analytical Modelling



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Simulation Modelling vs Analytical Modelling



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Analytical Modelling of the Grid

- Analytical models should be tractable
  - Small networks, simple scenarios, few packets, simplifications
- Hence, using analytical modelling for aspects of the Grid is far from trivial…. but worth the effort!

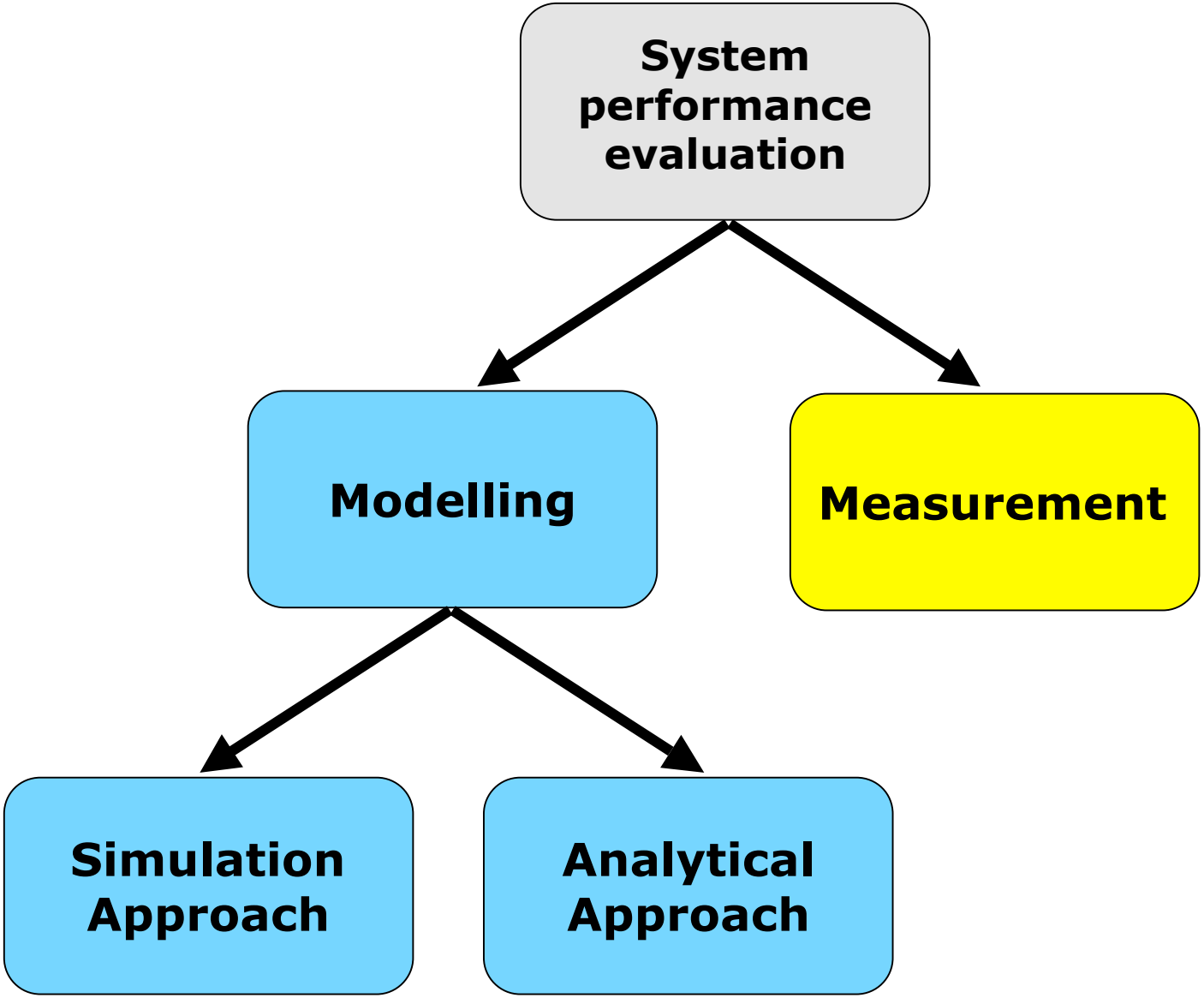
2 sentence summary

Challenging to conduct excellent analytical modelling of "traditional" networking systems

Even ***more*** challenging to conduct excellent analytical modelling of the Grid

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Overview



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