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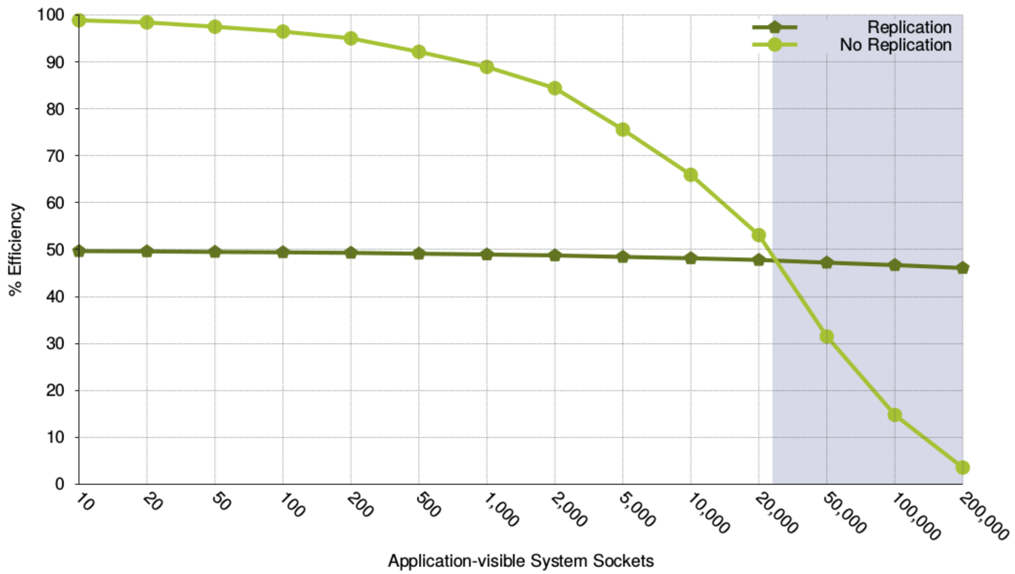
Corrected Gossip Algorithms for Fast Reliable Broadcast on Unreliable Systems

SPCL

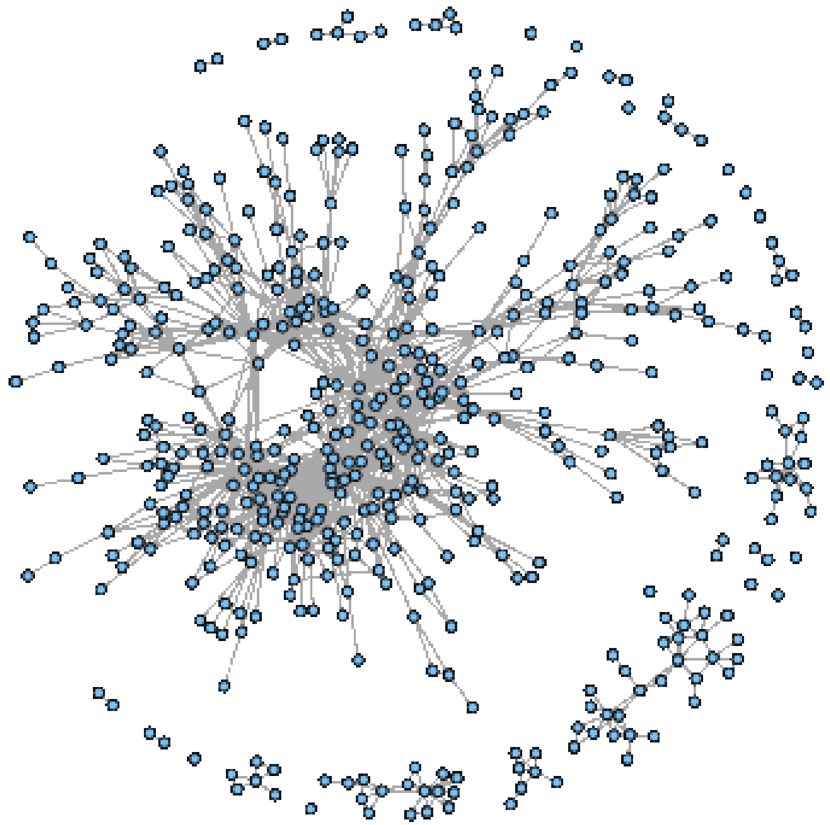
Failures in large-scale computing system

- **The number of components grows**
  - More and more transistors used
  - But also more racks, cabinets, cables, power supplies, etc.
  - Everything at a nearly constant reliability per part
- **Things will fail!**
  - Wang et al., 2010: "Peta-scale systems: MTBF 1.25 hours"
  - Brightwell et al., 2011: "Next generation systems must be designed to handle failures without interrupting the workloads on the system or crippling the efficiency of the resource."

    Checkpoint/restart will take longer MTBF!
- **We need to enable applications to survive failures**
  - … to reach ~~Petascale~~ Exascale!
  - Like they did for decades in distributed systems!

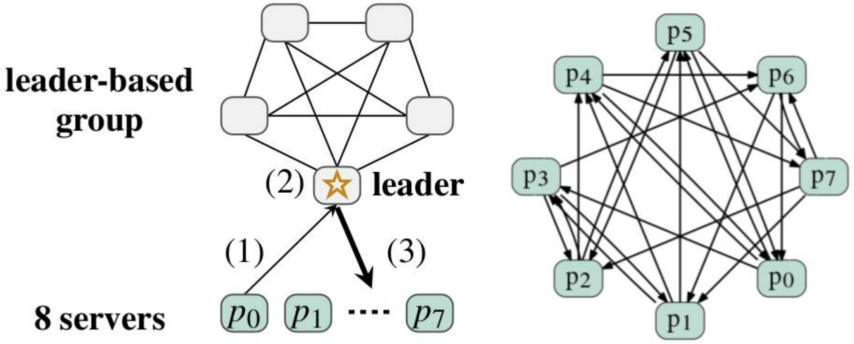


Distributed systems scenarios



- **Loosely consistent systems based on gossip**
  - Not all nodes always up to date
  - Sometimes eventual consistency
  - Weak ordering guarantees
  - Hard to control in general but may work well (e.g., load balancing)
- **Strongly consistent systems based on atomic broadcast/consensus**
  - Ordering guaranteed
  - Can survive up to k node failures, latency of k
  - Very limited in scalability

    Check our work on AllConcur at HPDC'17 though!
  - Usually low performance (limited to management tasks)
- **High-performance systems are specialized**
  - FARM – Fast Remote Memory (consistent FT database)
  - Corrected Gossip for group communications (this paper)



(a) Leader-based agreement (b) ALLCONCUR

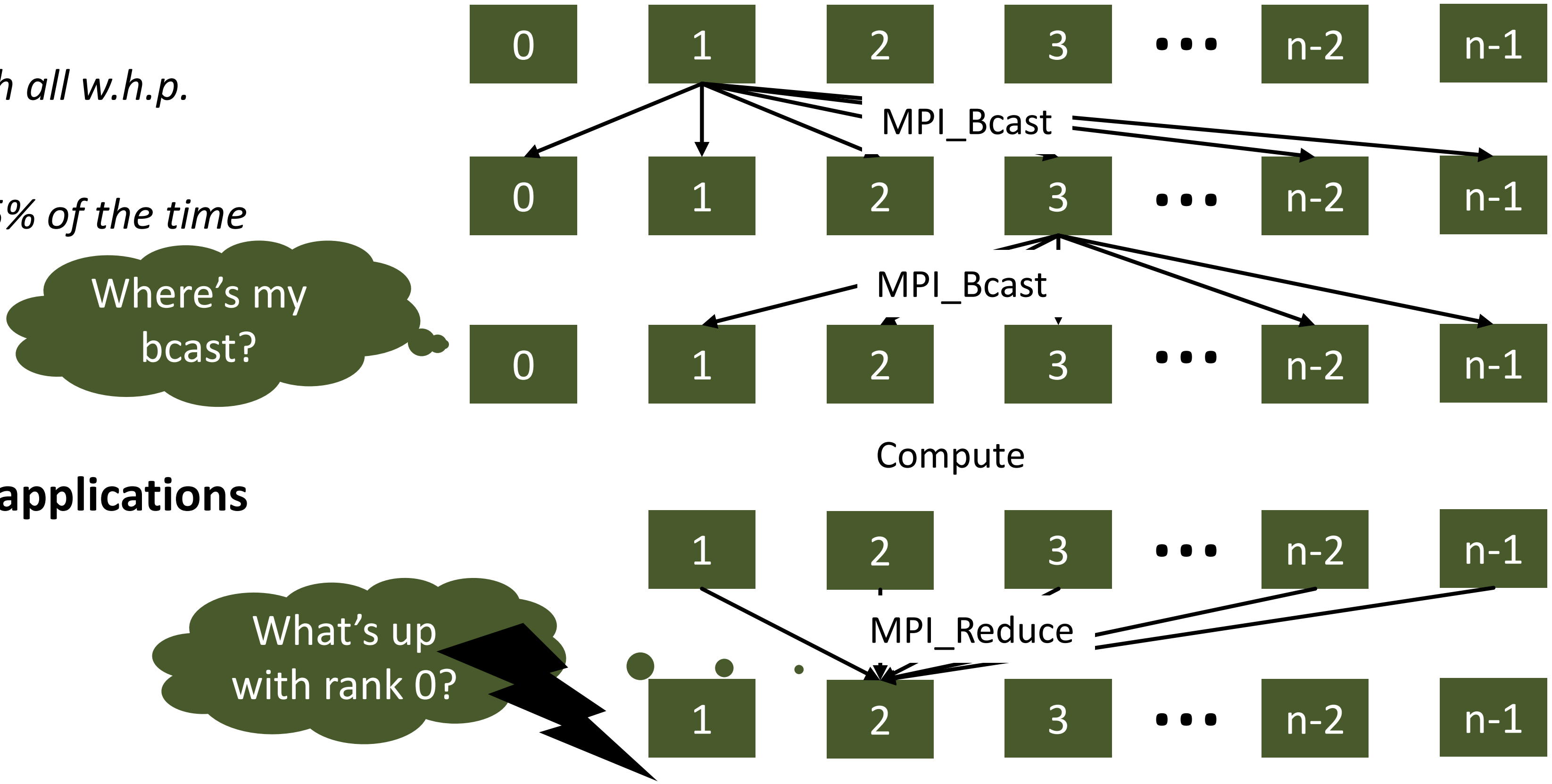
Specialized to HPC? Let's start with the simplest operation - broadcast

- **Gossip?**
  - If root or message received: send to random other node until some global time expires
  - Proven to be very effective
  - Not strongly consistent ☹
  - Nice theory

    needs 1.64 $\log_2 n$ rounds to reach all w.h.p.
  - But for N=1000

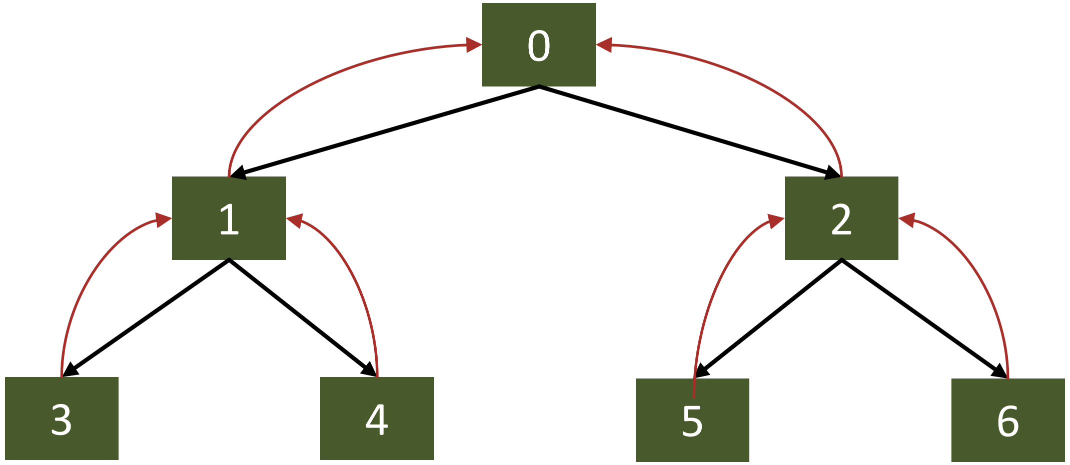
    17 rounds only color all nodes 95% of the time

- **Very problematic for BSP-style applications**



But how does FT-MPICH do this? Buntinas' FT broadcast

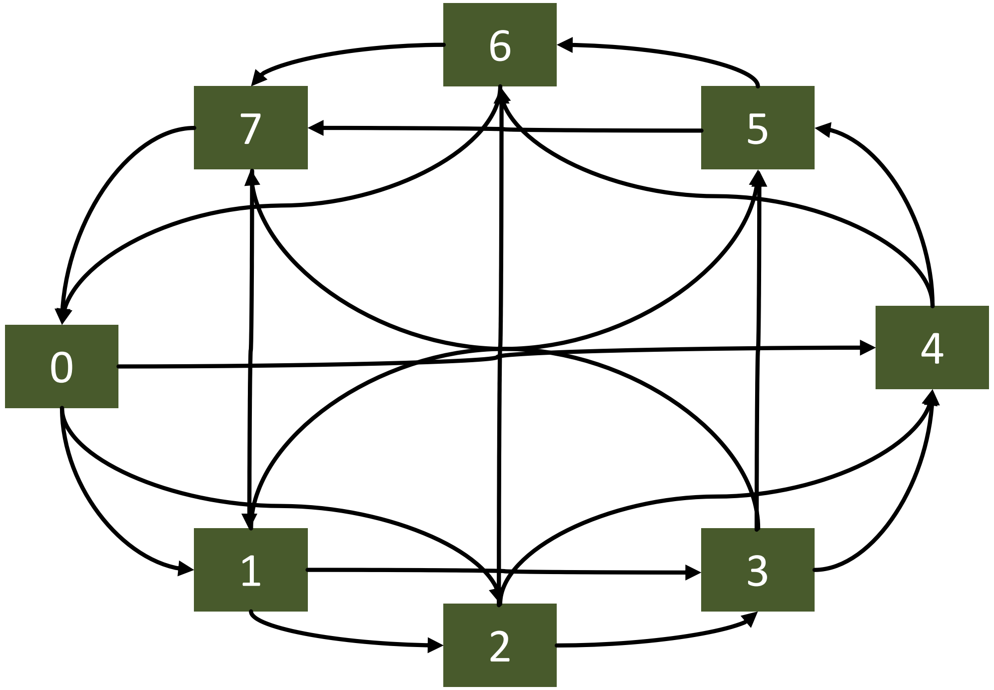
- Uses a dynamic tree, each message contains information about children at next levels
- Children propagate back to root, relying on local failure-detectors



- Complex tree rebuild protocol
- Root failure results in bcast never delivered
- At least 2 $\log_2 n$ depth!

But how does FT-OpenMPI do this? Binomial graph broadcast

- **Use fixed graph, send along redundant edges**
- **Binomial graphs: each node sends to and receives from $\log_2 n$ neighbors**



- **Can survive up to $\log_2 n$ worst-case node failures**
  - In practice much more (not worst-case)

How to beat these algorithms?

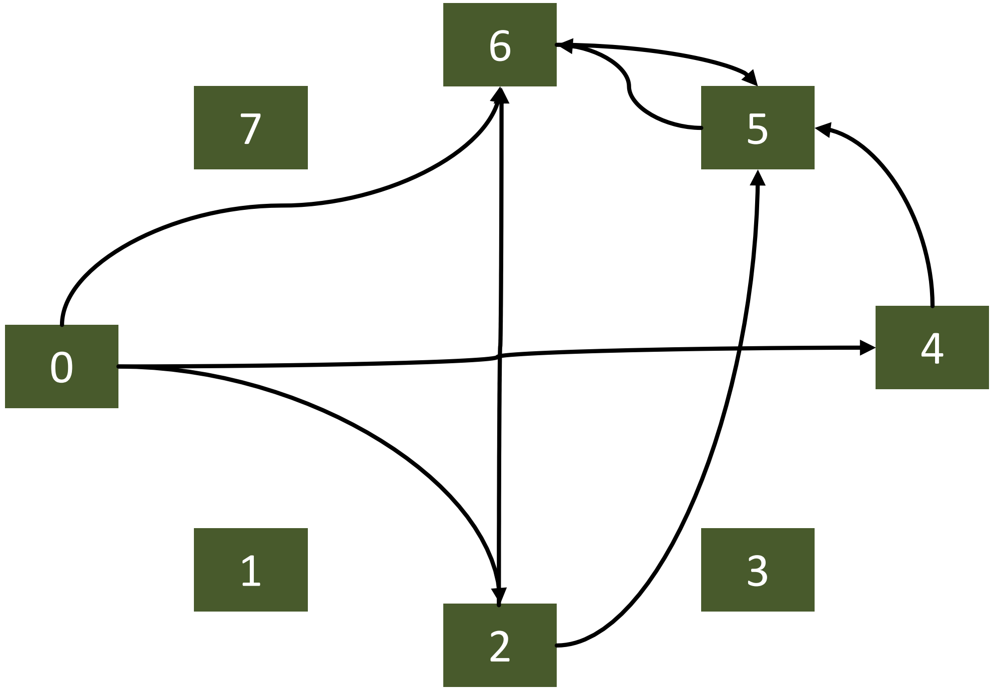
- **The power of randomness: gossip but <u>not just</u> gossip!**
- **Combine the probabilistic gossip protocol with a deterministic correction protocol**

Corrected gossip turns Monte Carlo style gossiping algorithms into Las Vegas style deterministic algorithms!

- **But what is a fault-tolerant broadcast? Root failures, arbitrary failures?**
  - Assuming fail-stop, four criteria need to be fulfilled:
  1. Integrity (all received messages have been sent)
  2. No duplicates (each sent message is received only once)
  3. Nonfaulty liveness (messages from a live node are received by all live nodes)
  4. Faulty liveness (messages sent from a failed node are either received by all or none live nodes)
- **We relax 3+4 a bit: three levels of consistency**
  1. Not consistent (we provide an improvement over normal gossiping)
  2. Nearly consistent (assuming no nodes fail during the correction phase, practical assumption)
  3. Fully consistent (any failures allowed)

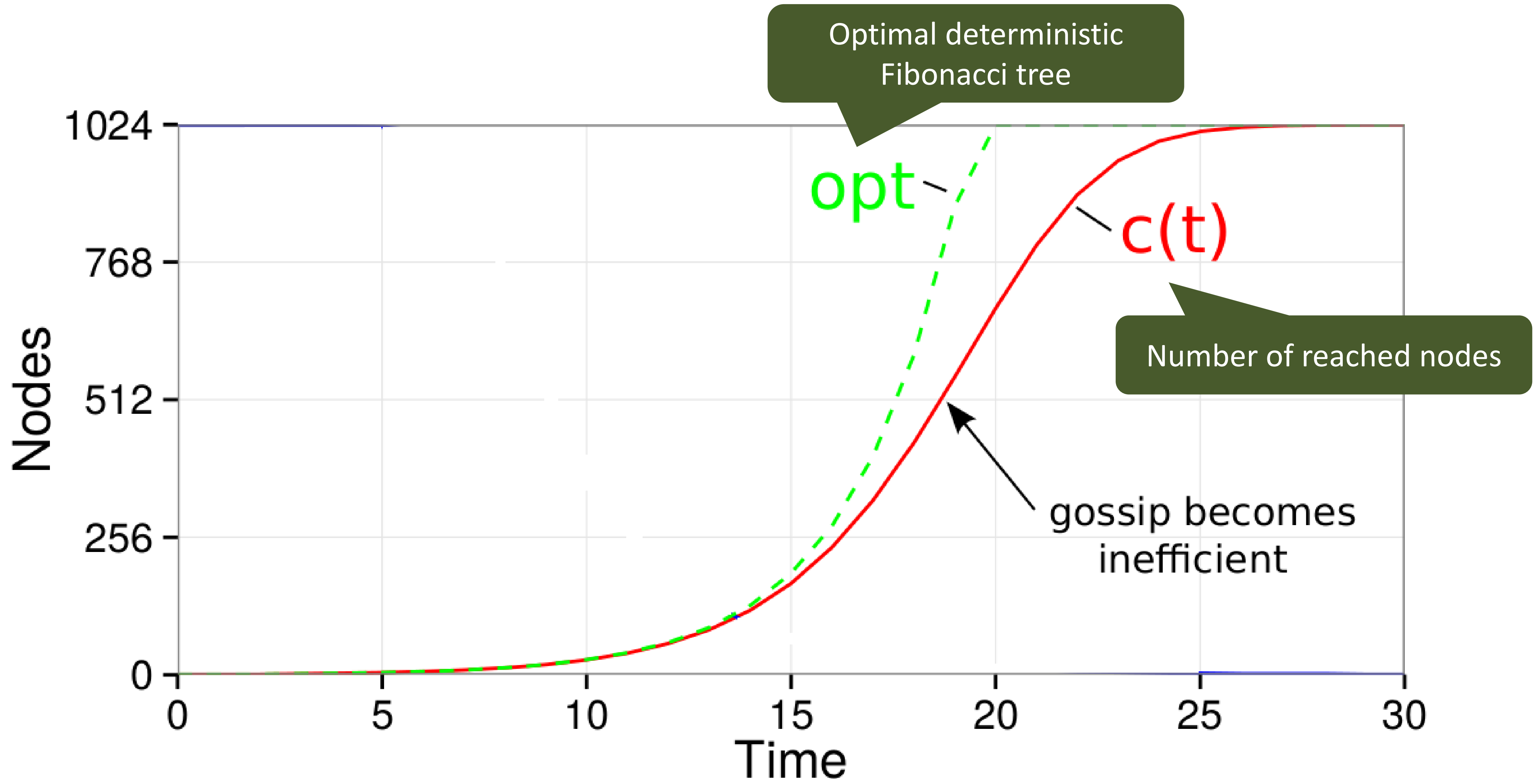
First algorithm: OCG (Opportunistic Corrected Gossip)

- **Not consistent, works w.h.p. --- let's first consider just gossiping**



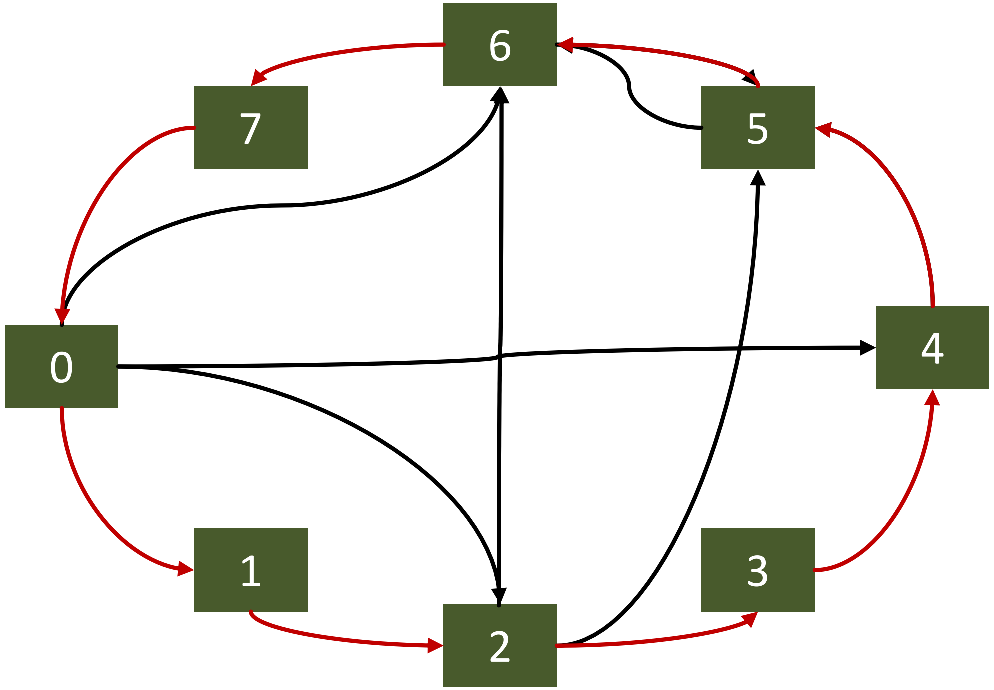
Are all these redundant messages efficient?

First algorithm: OCG (Opportunistic Corrected Gossip)



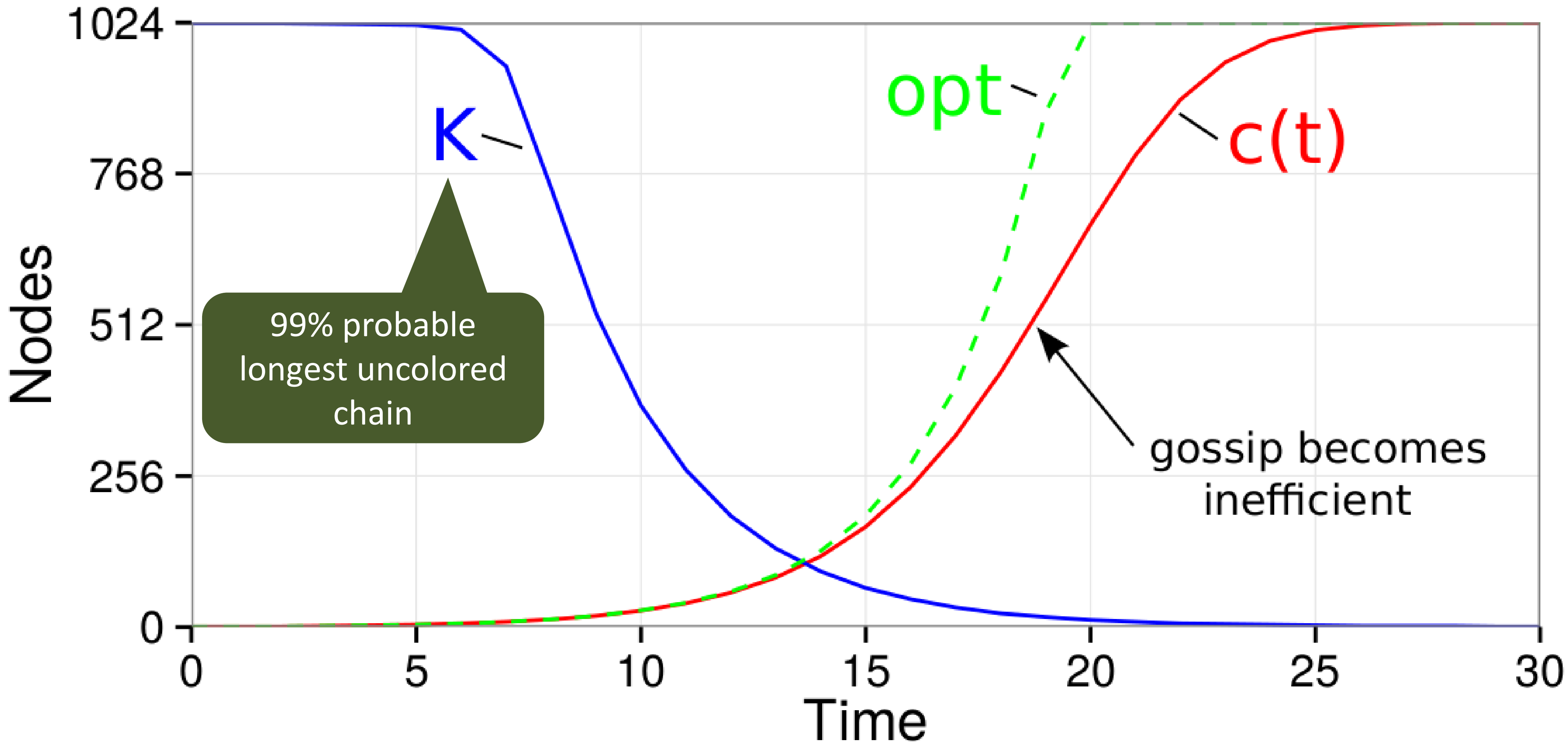
First algorithm: OCG (Opportunistic Corrected Gossip)

- **OCG main idea: run gossip for a while and then switch to a ring-correction protocol**
  - Every node that received a message sends it to (rank + 1) % nranks



- **Each message may be received twice**
  - But this depends on when we switch! But what is the longest uncolored chain?

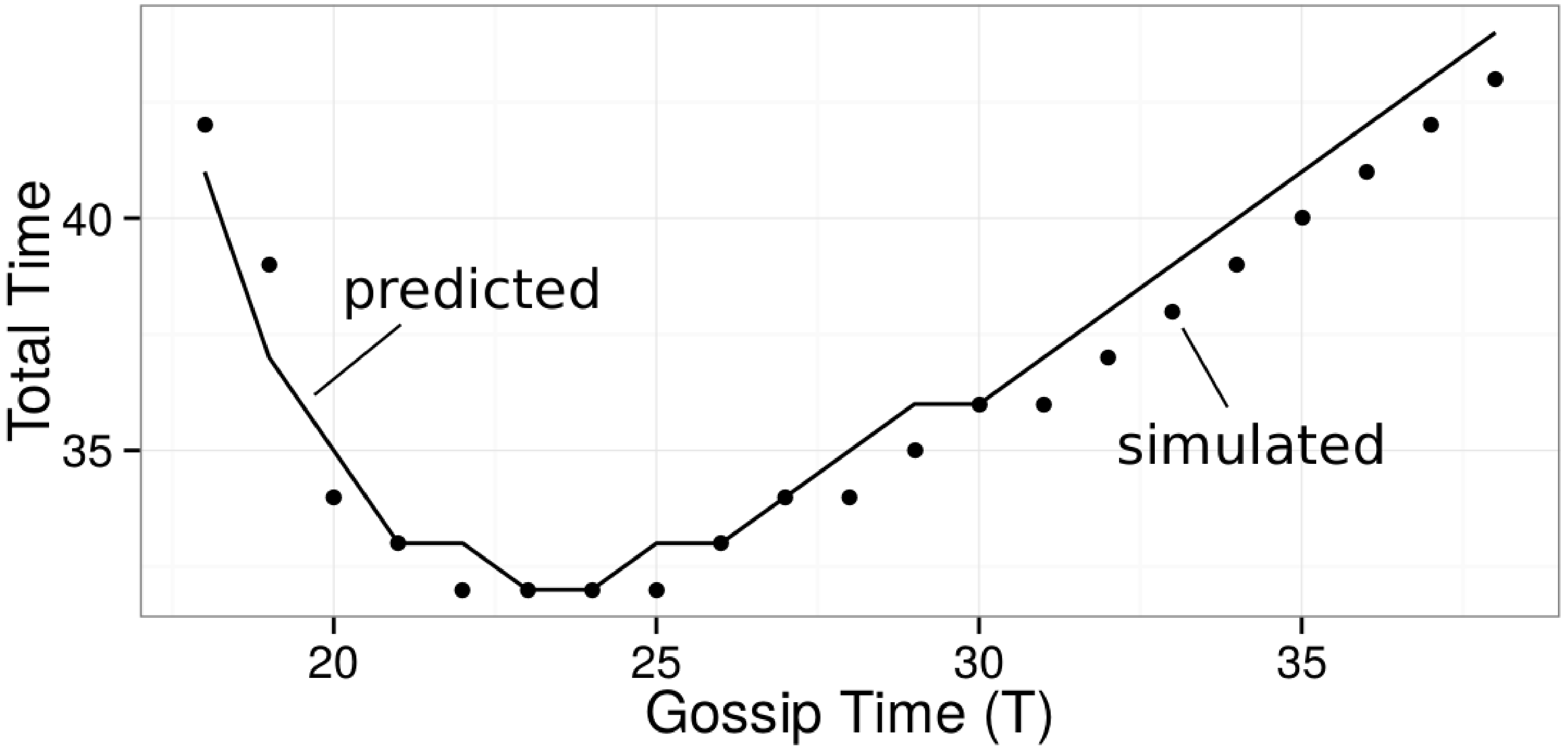
The longest uncolored chain!



First algorithm: OCG (Opportunistic Corrected Gossip)

- **When to switch from gossip to correction?**
  - Well, when the expected number of correction steps is small and gossip is inefficient
- **We can bound the probability of a longest chain of length k**
  - In terms of the LogP parameters, T (gossip time), and N (nranks)

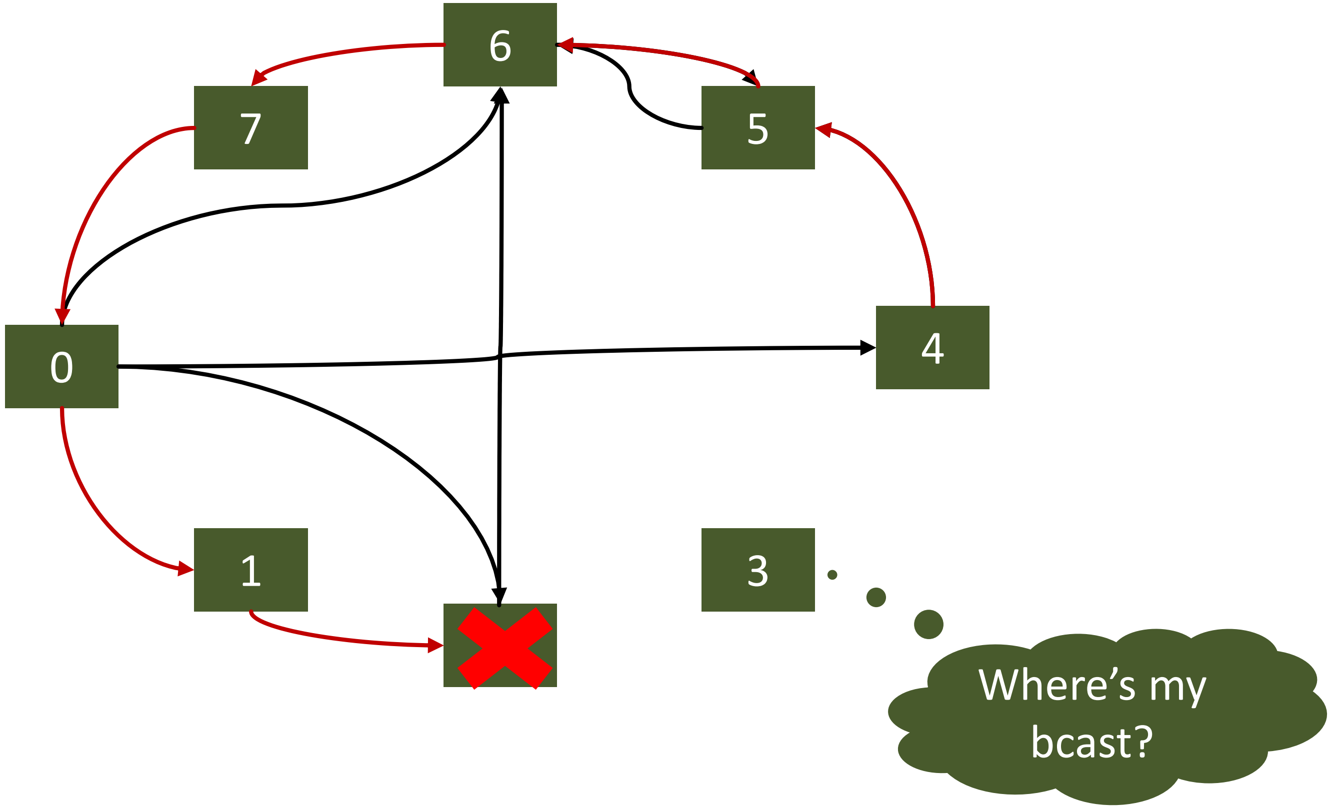
$$T_{opt}^{OCG} = \underset{T}{\operatorname{argmin}}(T + 2L + (2 + \overline{K})O)$$



The optimal time to switch depends on L, O, and N

OCG Consistency

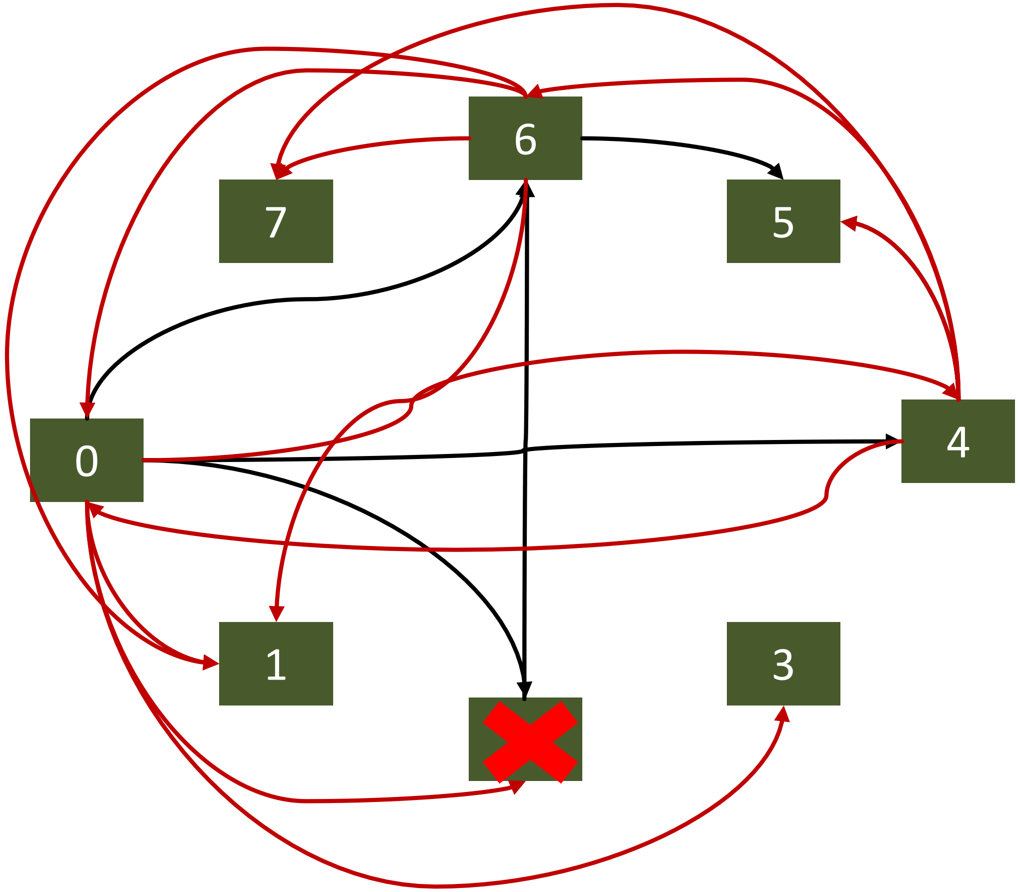
- **OCG is more efficient than gossip but does not guarantee that all nodes are reached (even w/o failures)**



- **So we need to check that they were actually reached!**

Second algorithm: CCG (Checked Corrected Gossip)

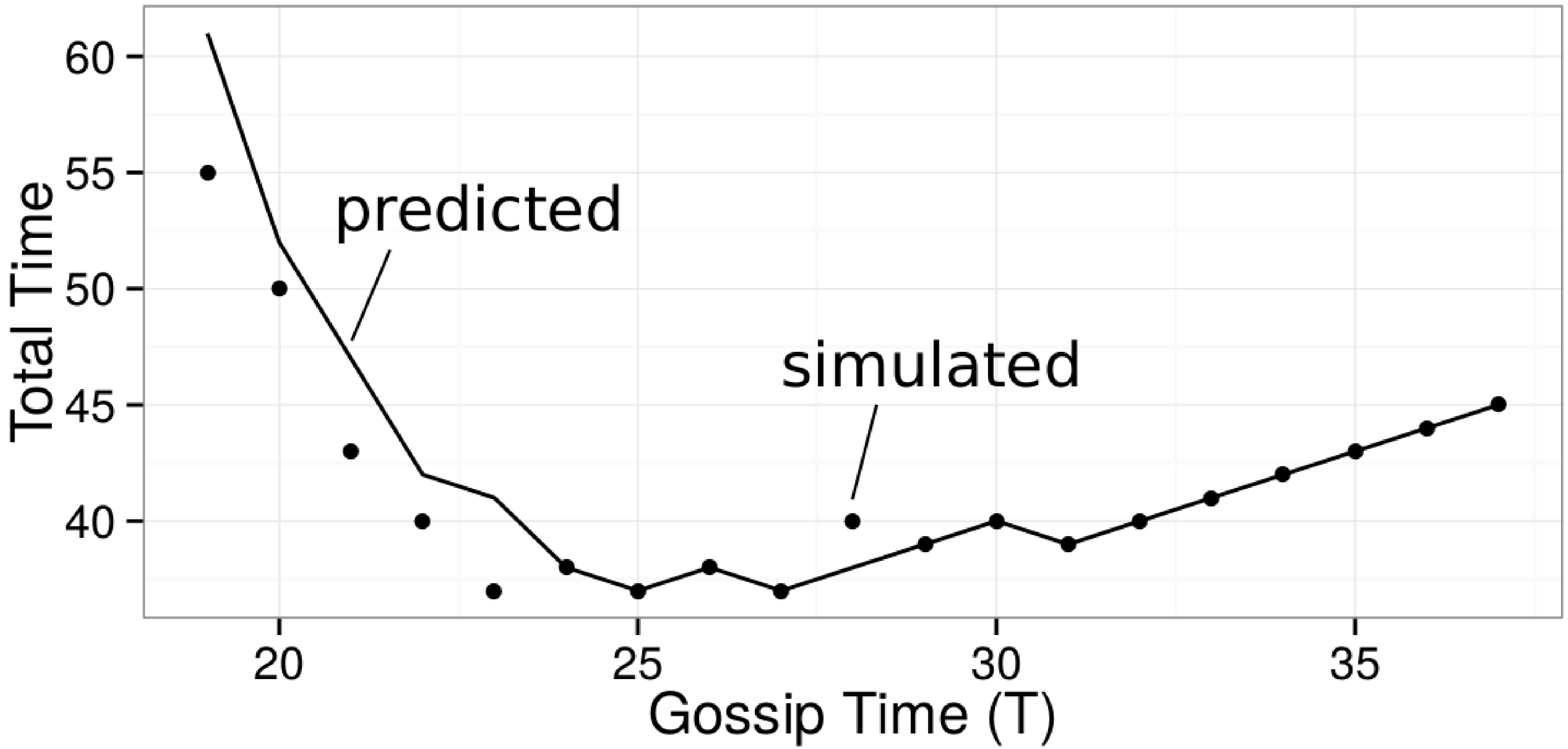
- **CCG sends to the next node until it sent to a node it received from (i.e., knows that node was alive!)**
  - Since the node it received from also sent, it "knows" that all other nodes have been covered!



- **CCG guarantees that all nodes are reached unless a node dies in the middle of the correction phase!**
  - And another node assumes it finished its job!

Second algorithm: CCG (Checked Corrected Gossip)

- **When to switch from gossip to correction?**



- **A bit later than OCG**

Third algorithm: FCG (Failure-proof Corrected Gossip)

- **FCG can protect from f failures – similar to CCG but instead of aborting to send when heard from one, it waits to hear from f+1 other nodes!**
- **So any f nodes can fail and it will still succeed (keep sending)**

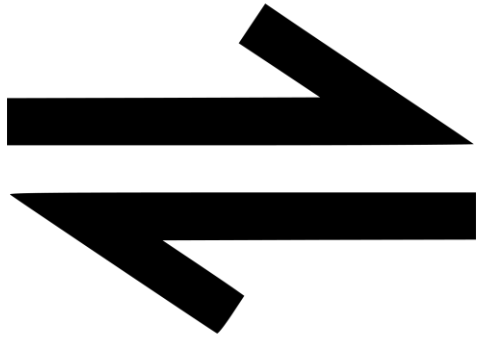
- **Wait, what if there are less than f+1 nodes reached during gossip and they somehow die in the middle of the protocol?**
  - So we need to involve the non-gossip-colored nodes
  - They will wait to hear from a gossip-colored nodes to exit
  - If no such exit signal comes within a timeout period, panic!
  - In panic mode, send to every other node
  - Every node that receives panic messages also panics
  - This guarantees consistency (at a high cost)

- **Panic mode is extremely unlikely in practice (much less likely than the failing of binomial graphs)**
  - Likelihood can be reduced arbitrarily with gossiping time!
  - So panic is just a theoretical concern (to proof correctness)

Observations and Optimizations

- **Why the ring topology?**
  - One could choose different topologies (e.g., broadcast trees), we did not find a better practical one
  - This seems to be an interesting research topic

- **Optimization: bidirectional**
  - In fact, all our algorithms send backwards and forward along the ring
    We skipped it to simplify the explanation
  - Buys a factor of two, very practical (very impactful for CCG/FCG)



- **Does the principle generalize**
  - We believe so, more algorithms to come!

- **Both the binomial graphs and FCG require to pick an f, is there a total consistency?**
  - Only if f=N-2, which is not practical
  - Yet, both algorithms can be configured for an arbitrarily high success probability!

Case study: TSUBAME 2.0

- **TiTech machine, published failure logs**
- **MTBF = 18304 hours**
  - Assume 12 hour run on 4096 nodes = 2.69 failures
- **We compare all algorithms and report**
  1. Expected latency
  2. Expected work
  3. Expected inconsistency

  For CCG/OCG/FCG, we simulate until the nonparameric CI was within 2% of the median

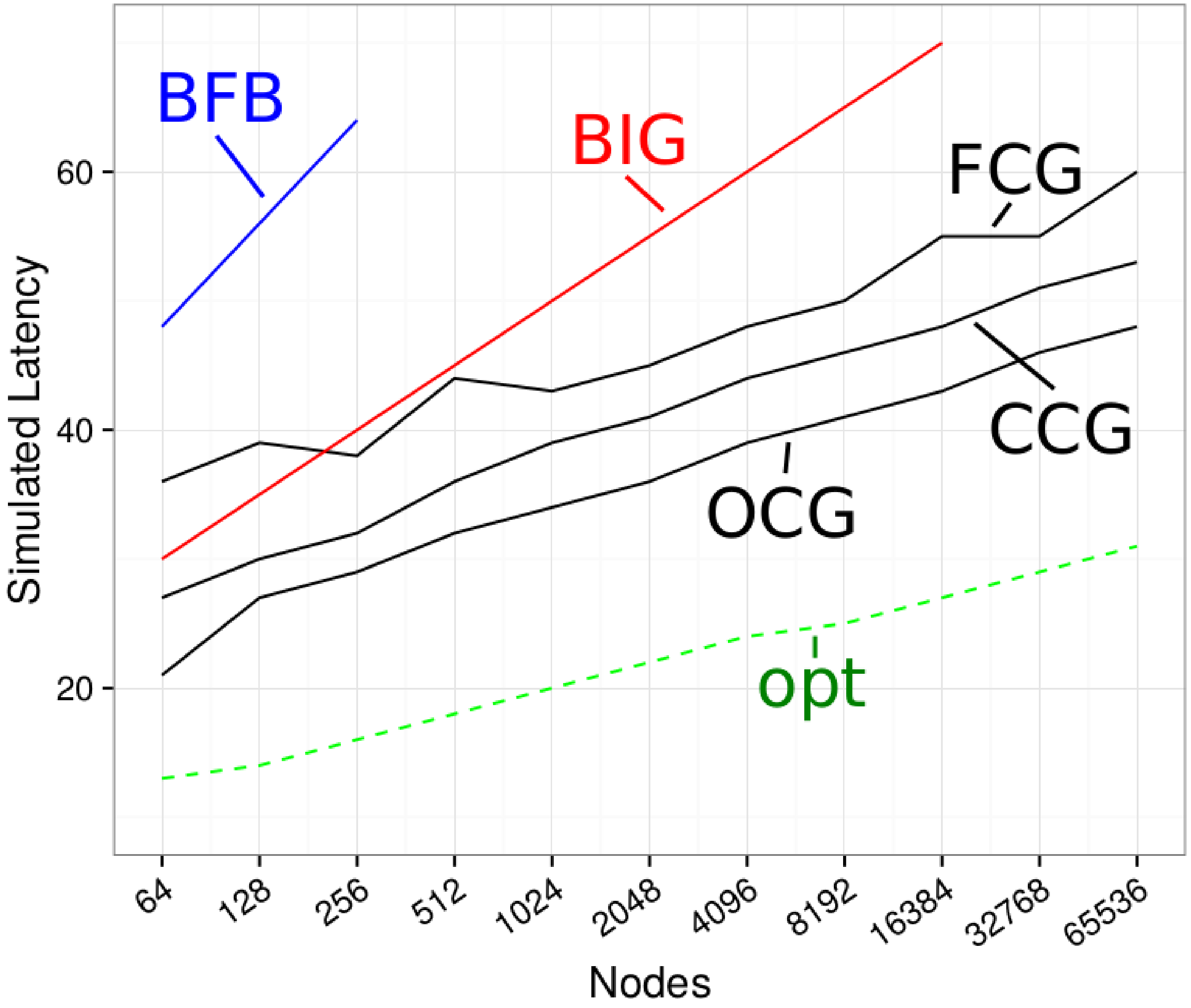
Gossip

Binomial Graphs

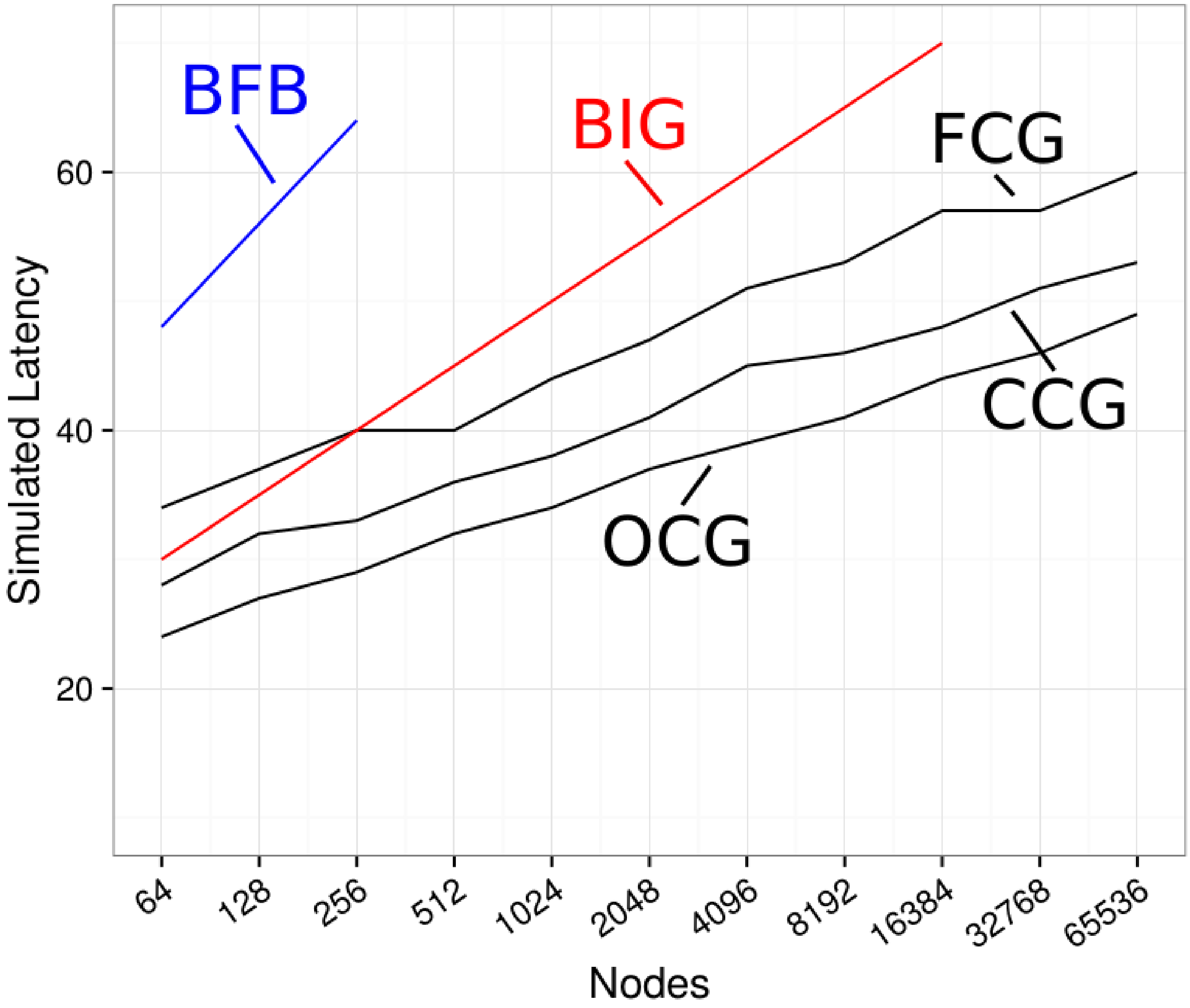
Buntinas' Tree

algorithm	$\hat{f}$	T	lat	work	incon.
GOS [12]	0				
GOS [12]	3				
OCG	0				
OCG	3				
CCG	0				
CCG	3				
FCG	0				
FCG	3				
BIG [2]	0				
BIG [2]	3				
BFB [8]	0				
BFB [8]	3				

Scaling – Without failures



Scaling – With failures (expected for 12 hours on TSUBAME 2.0)



Summary and Conclusions

- **New principle to implement fault-tolerant group communications**
  - Combines randomness and determinism – Las Vegas style algorithms
- **Three versions with growing consistency**
  - Opportunistic Corrected Gossip
  - Checked Corrected Gossip
  - Failure-proof Corrected Gossip
- **Analytic models to selecting parameters**
  - Fast to compute gossiping time
- **Now we need to see if it's practical**
  - May need some hardware support

    In a trivial implementation, wasted o dominate!

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