Topology Change Tolerant Routing for Delay Tolerant Networks

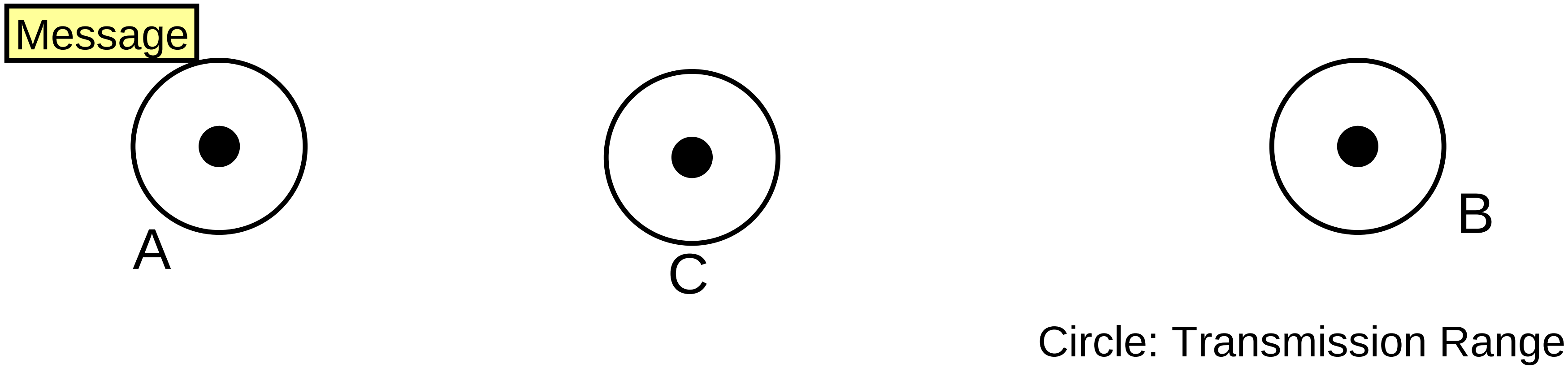
Hideya Ochiai   Hiroshi Esaki
The University of Tokyo / NICT

Outline

- Introduction
- Topology Change Tolerant Routing
  - Next hop selection and message forwarding
  - Potential-field computation
- Prototype Implementation
- Conclusion

Background and Goal

- Communication over intermittently connected links
  - Message delivery over cyclic mobile node
  - Application of Delay Tolerant Networks (DTN)

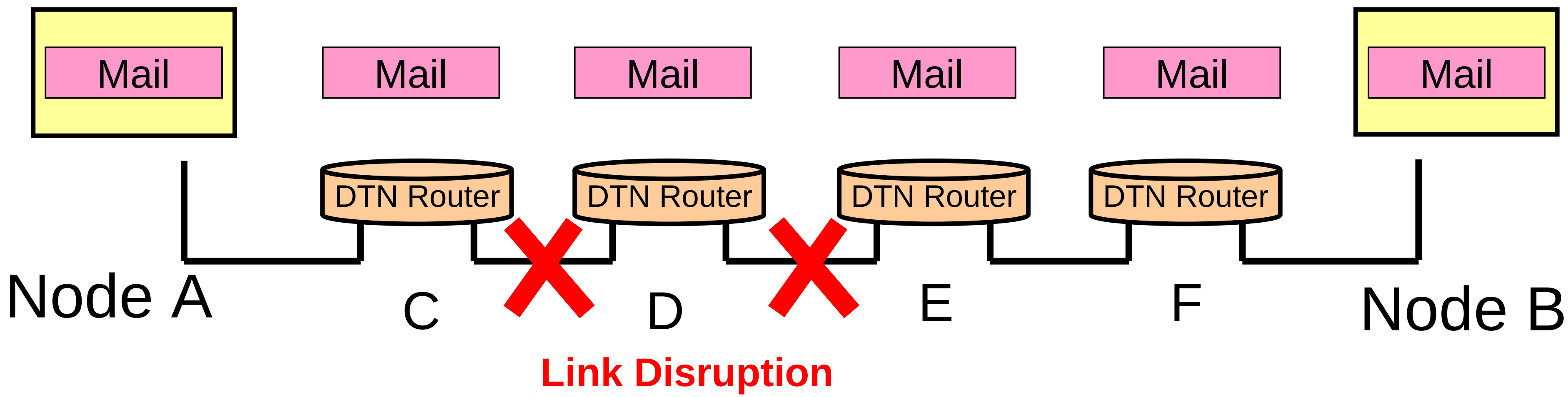


- Proposal: Message Routing in DTNs
  - where physical topology frequently changes

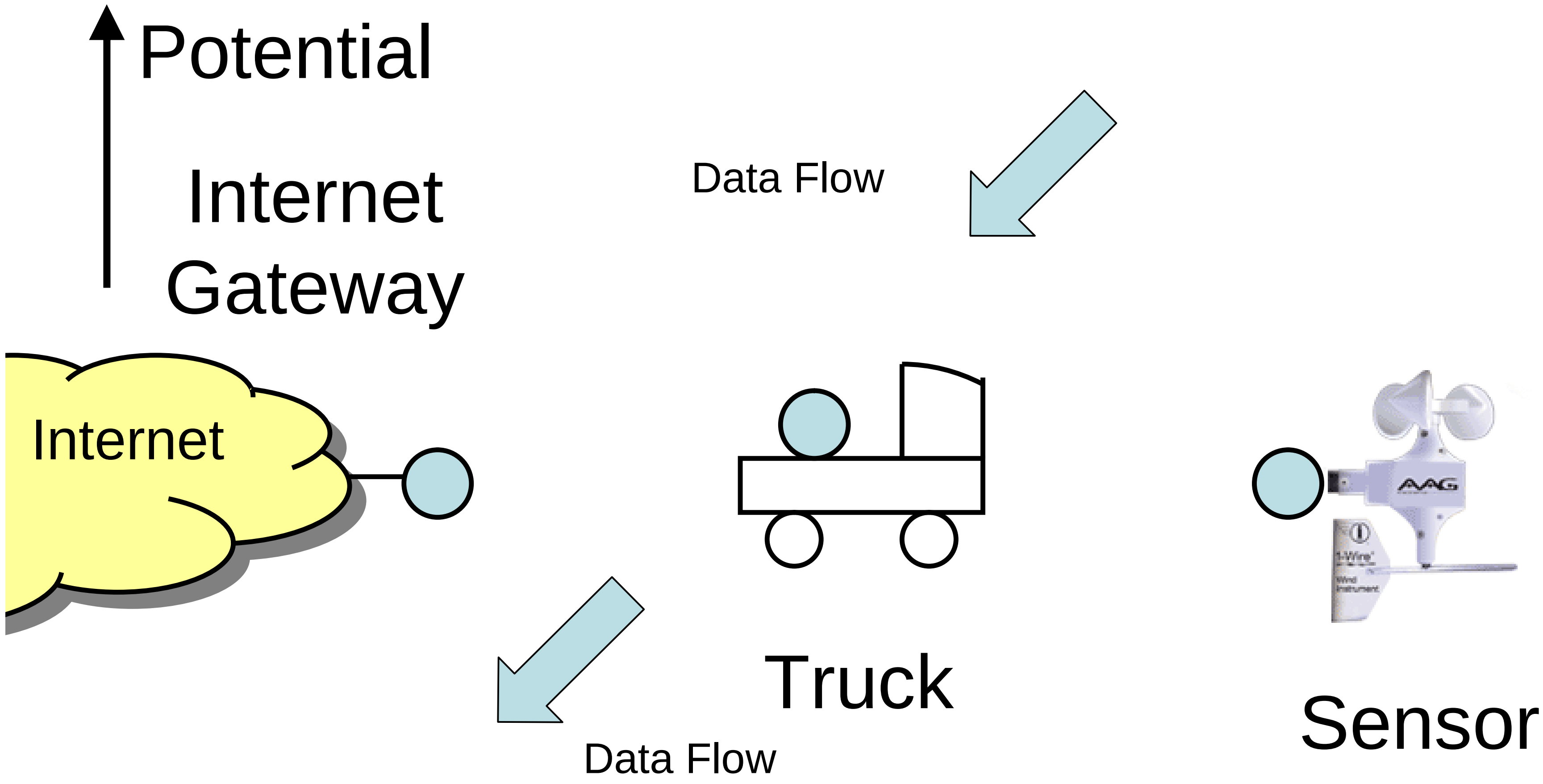
  I.e., intermittent connectivity

Delay Tolerant Networks

- Message Delivery Scheme
  - Hop-by-Hop Message Delivery
  - End-to-End Asynchronous Communication
  - Store-Carry-Forward



Approach: Potential-Based Routing (PBR)



Delivering sensor data to the Internet gateway

Wireless Device

Outline

- Introduction
- Topology Change Tolerant Routing
  - Next hop selection and message forwarding
  - Potential-field computation
- Prototype Implementation
- Conclusion

Terminology

- A set of nodes: N
- A node: $n \in N$
- A set of neighbors: $nbr(n)$ Nodes that are within direct transmission range
- A neighbor node: $k \in nbr(n)$
- Potential for destination d at n : $V^d(n) \in \mathrm{R}$
- with explicit t : $V^d(n,t)$
- The next hop nodes for destination d at n :

$$nexthop^d(n)$$

<< TCTR >>
Next hop selection and message forwarding

Force at node n toward node $k \in nbr(n)$:

$$F_k^d(n) \equiv V^d(n) - V^d(k)$$

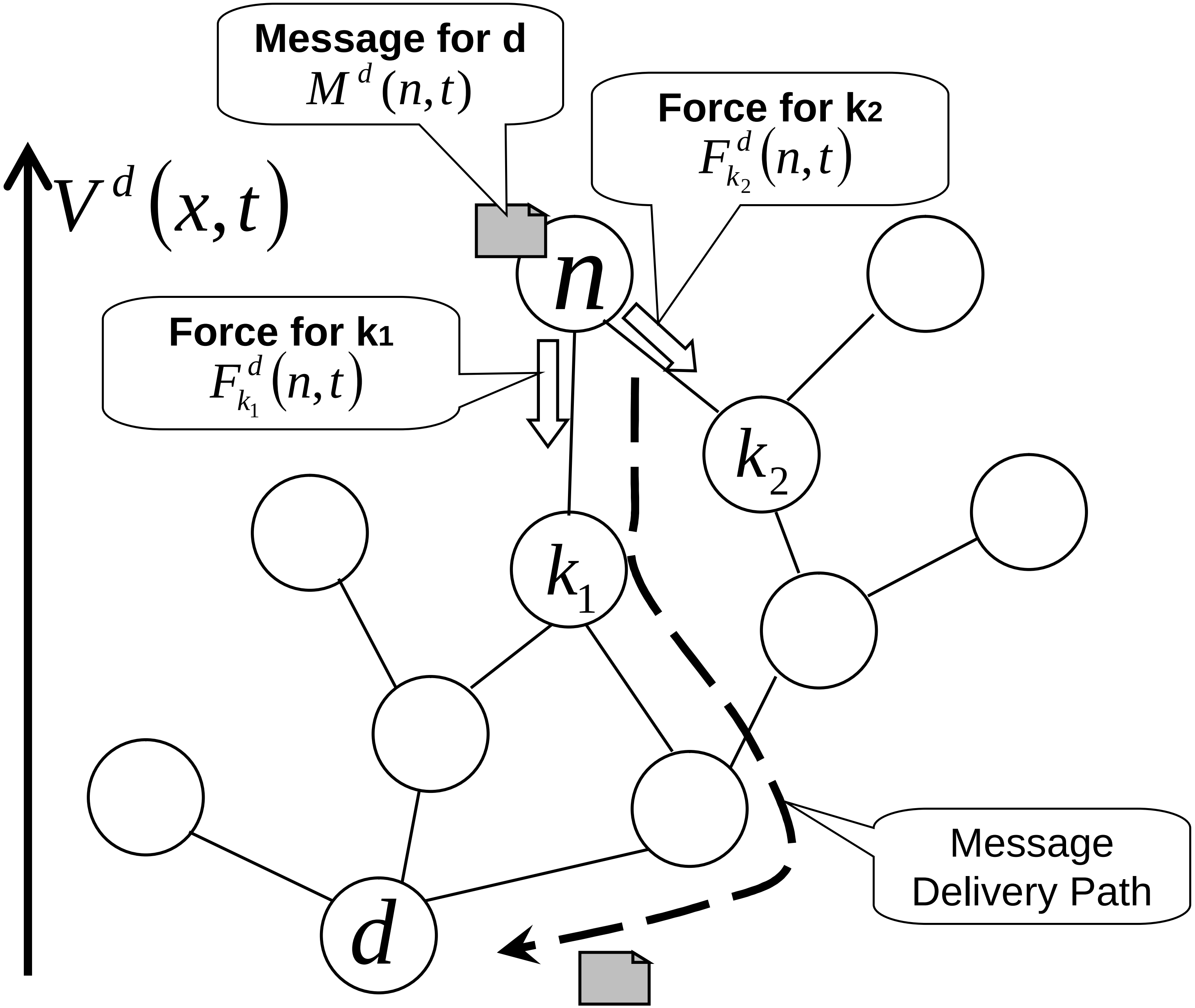
Next hop nodes for destination d :

$$\left(\forall k \in nbr(n)\ F_k^d(n) < \alpha\right) \rightarrow nexthop^d(n) = \Phi$$

Empty Set

$$\left(\exists k \in nbr(n)\ F_k^d(n) \geq \alpha\right)$$
$$\rightarrow nexthop^d(n) = \left\{k \mid F_k^d(n) = \max_{j \in nbr(n)} F_j^d(n)\right\}$$

α : threshold (const.)



$$\left\{F^d_{k_1}(n,t) > F^d_{k_2}(n,t)\right\} \wedge \left\{F^d_{k_1}(n,t) > \alpha\right\} \rightarrow nexthop^d(n,t) = k_1$$

<< TCTR >>
Potential-Field Computation

Definition by a recurrence formula

$$V^{d}(n,t+1) = V^{d}(n,t) + D \min_{k \in nbr(n)} \left\{ V^{d}(k,t) - V^{d}(n,t) \right\} + \rho$$

Boundary condition $\quad \forall t \forall d \in N, V^{d}(d,t) = 0$

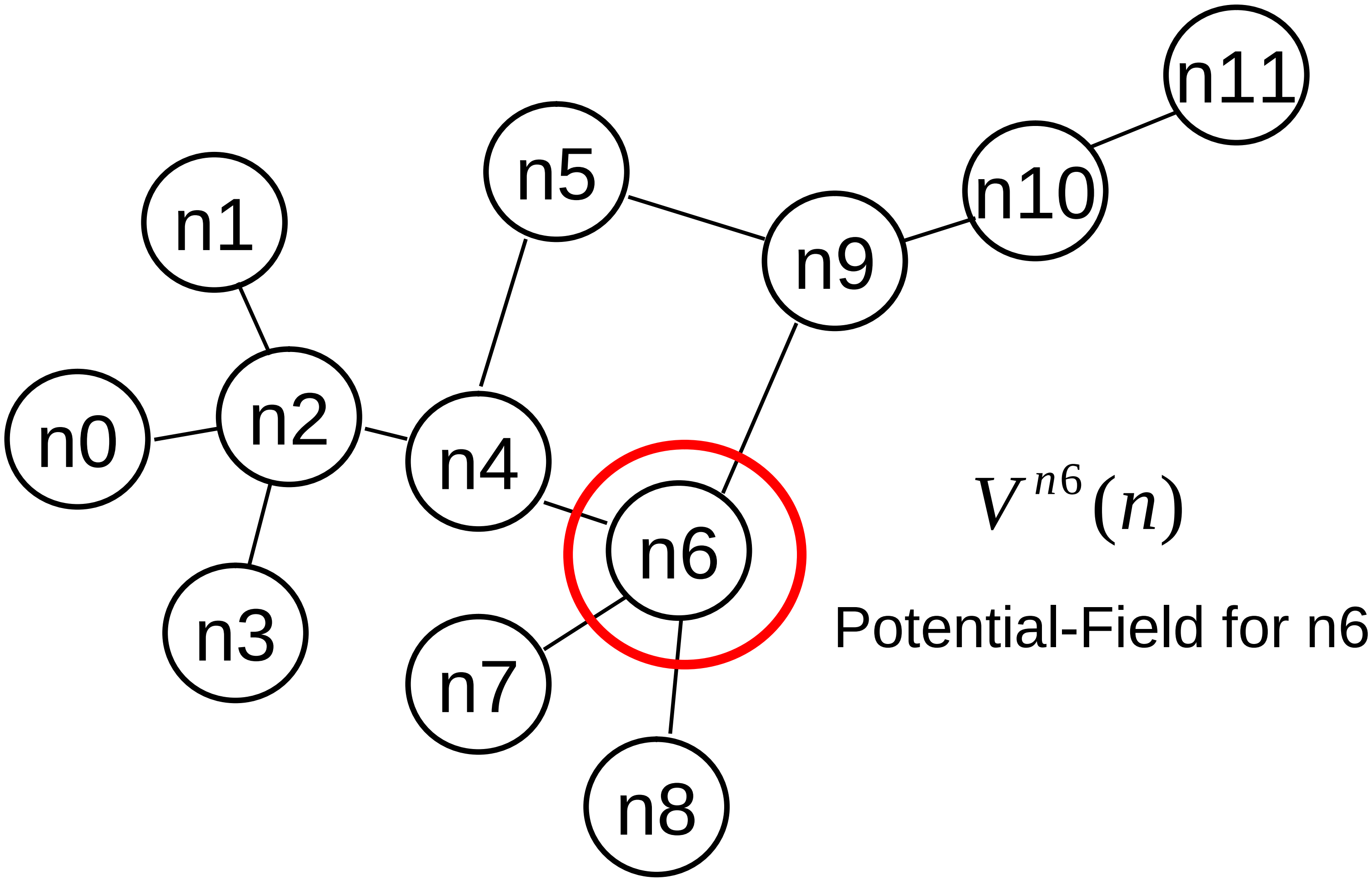
Initial condition $\quad \forall n, d \in N, V^{d}(n,0) = 0$

D : const. $\quad 0 < D << 1$

ρ : const. $\quad 0 < \rho < D$

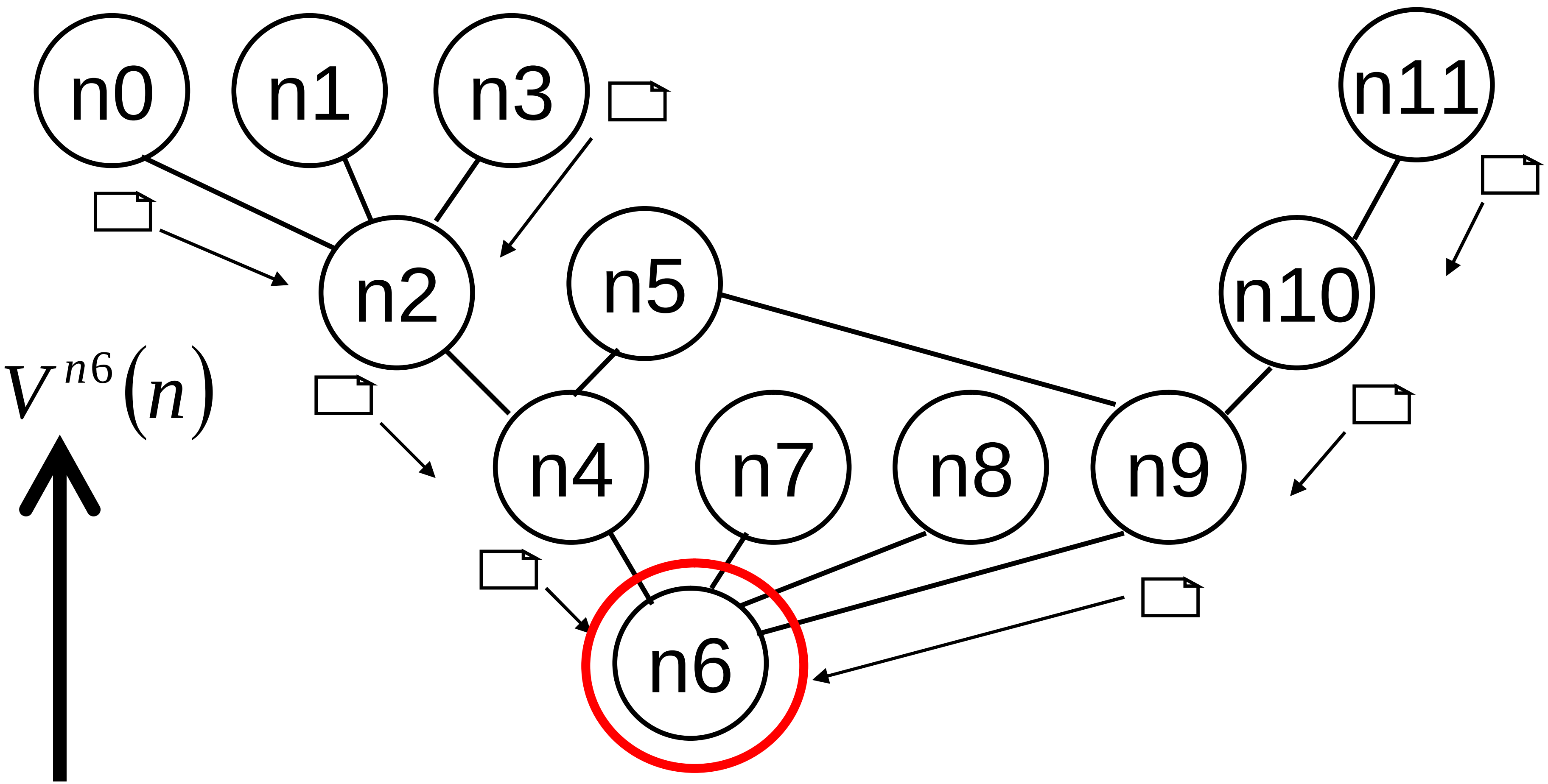
<< TCTR >>

Potential-Field Computation and Message Delivery (1/6)



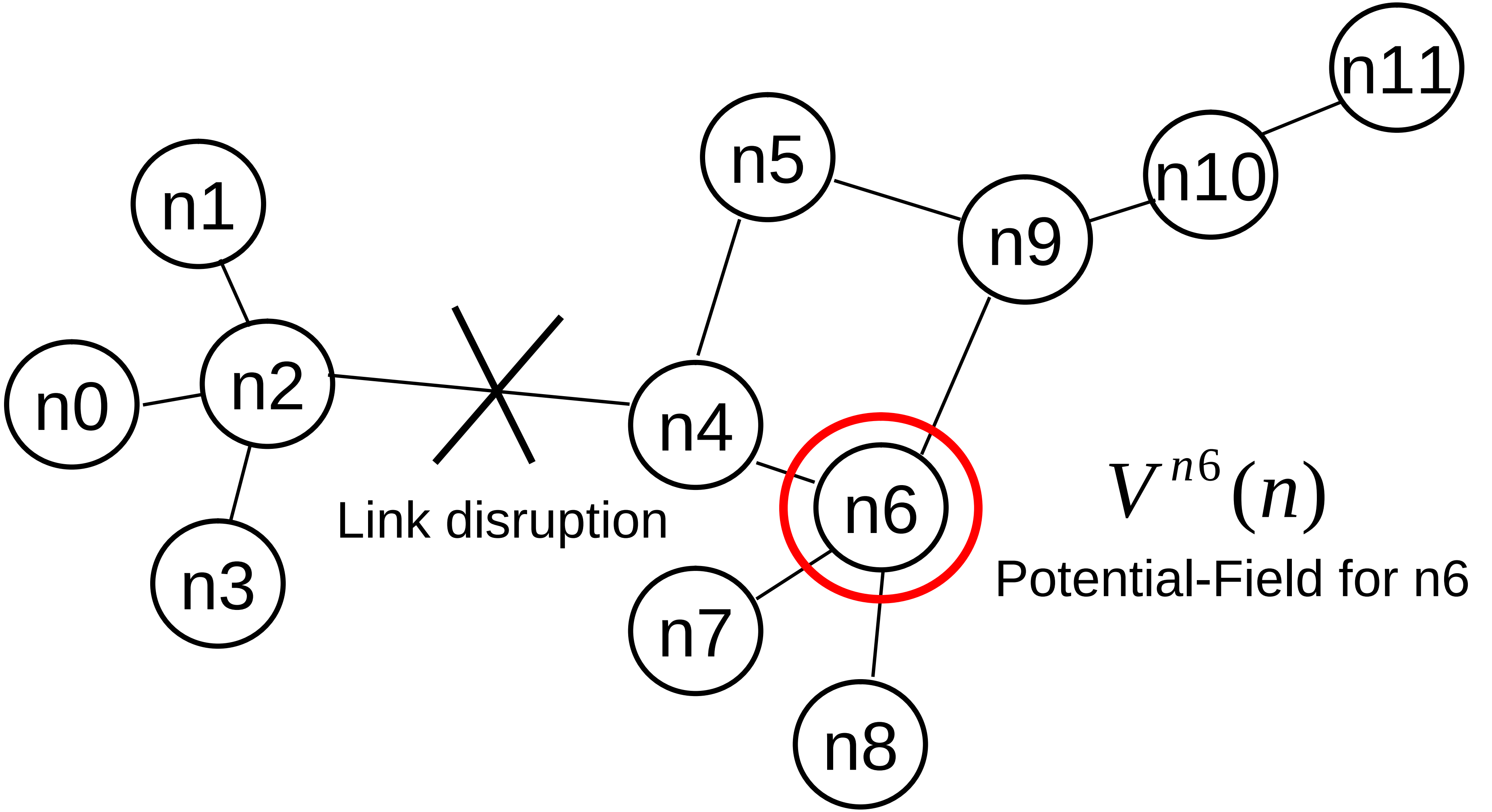
Connected Network

<< TCTR >>
Potential-Field Computation and Message Delivery (2/6)



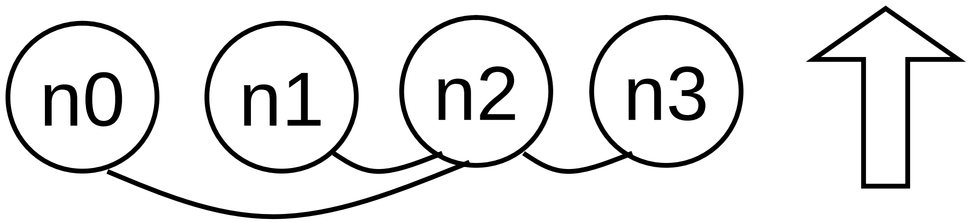
<< TCTR >>

Potential-Field Computation and Message Delivery (3/6)



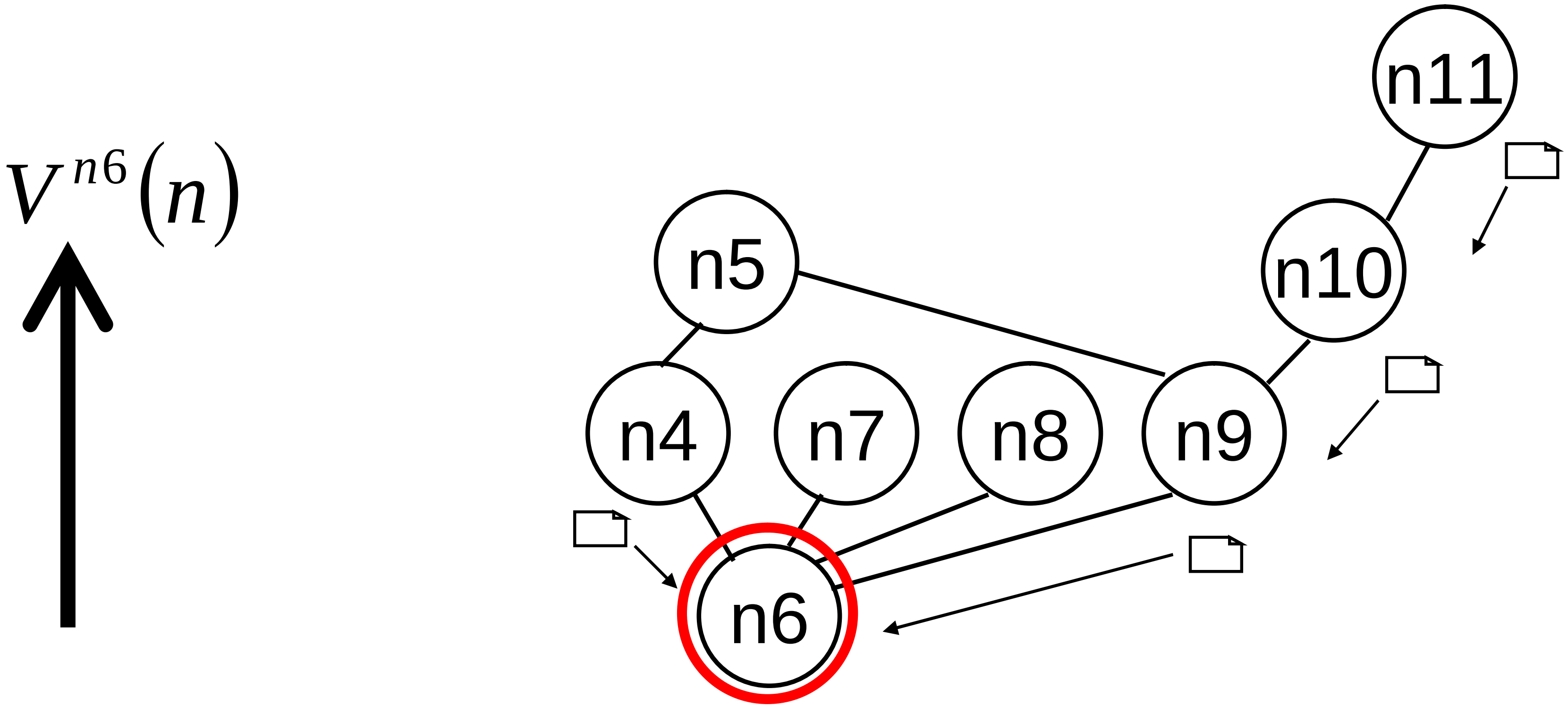
When a link disrupts

<< TCTR >>
Potential-Field Computation and Message Delivery (4/6)

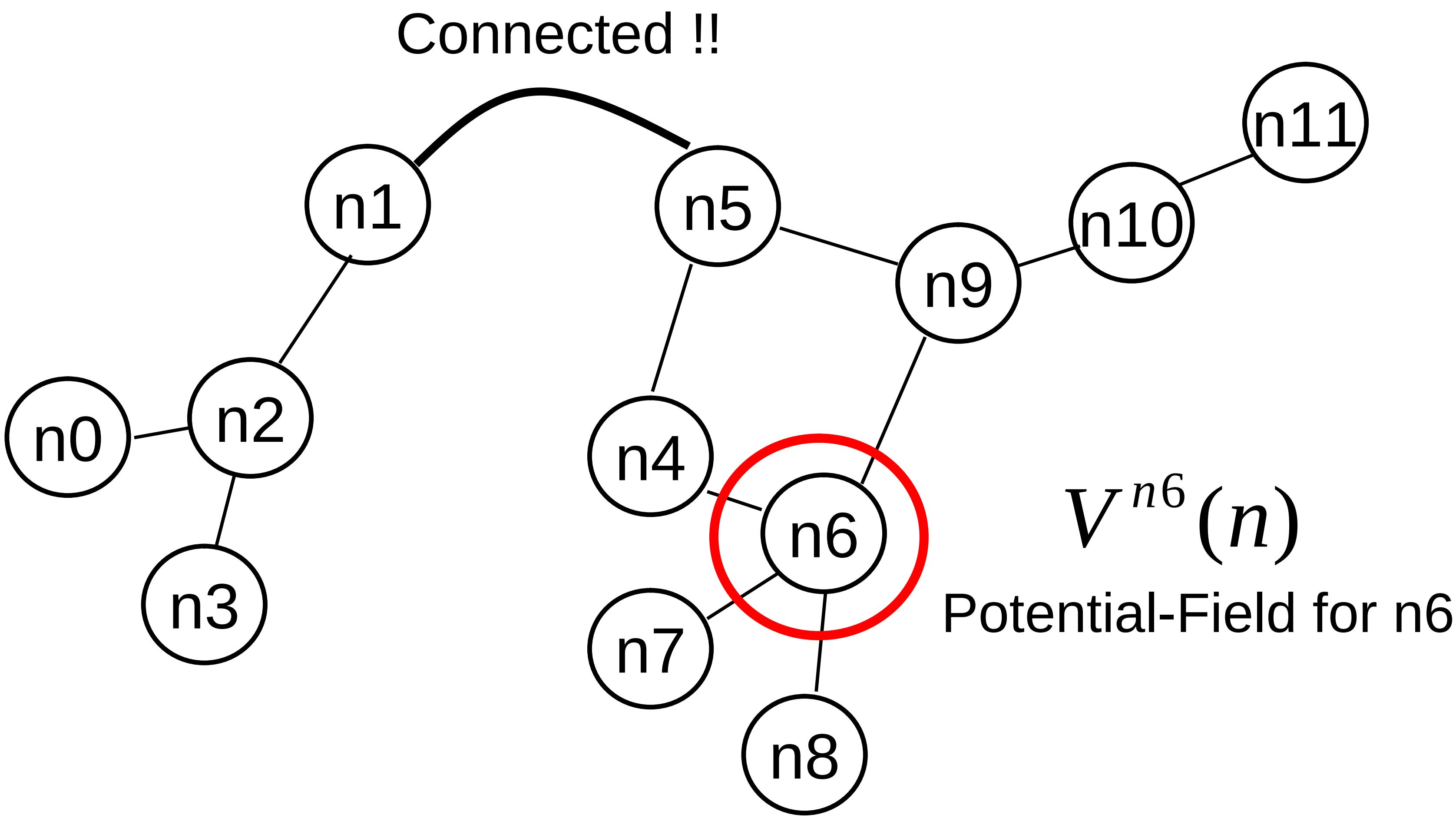


$$\frac{\partial V^{n6}(n,t)}{\partial t} = \rho$$

Increase at speed ρ

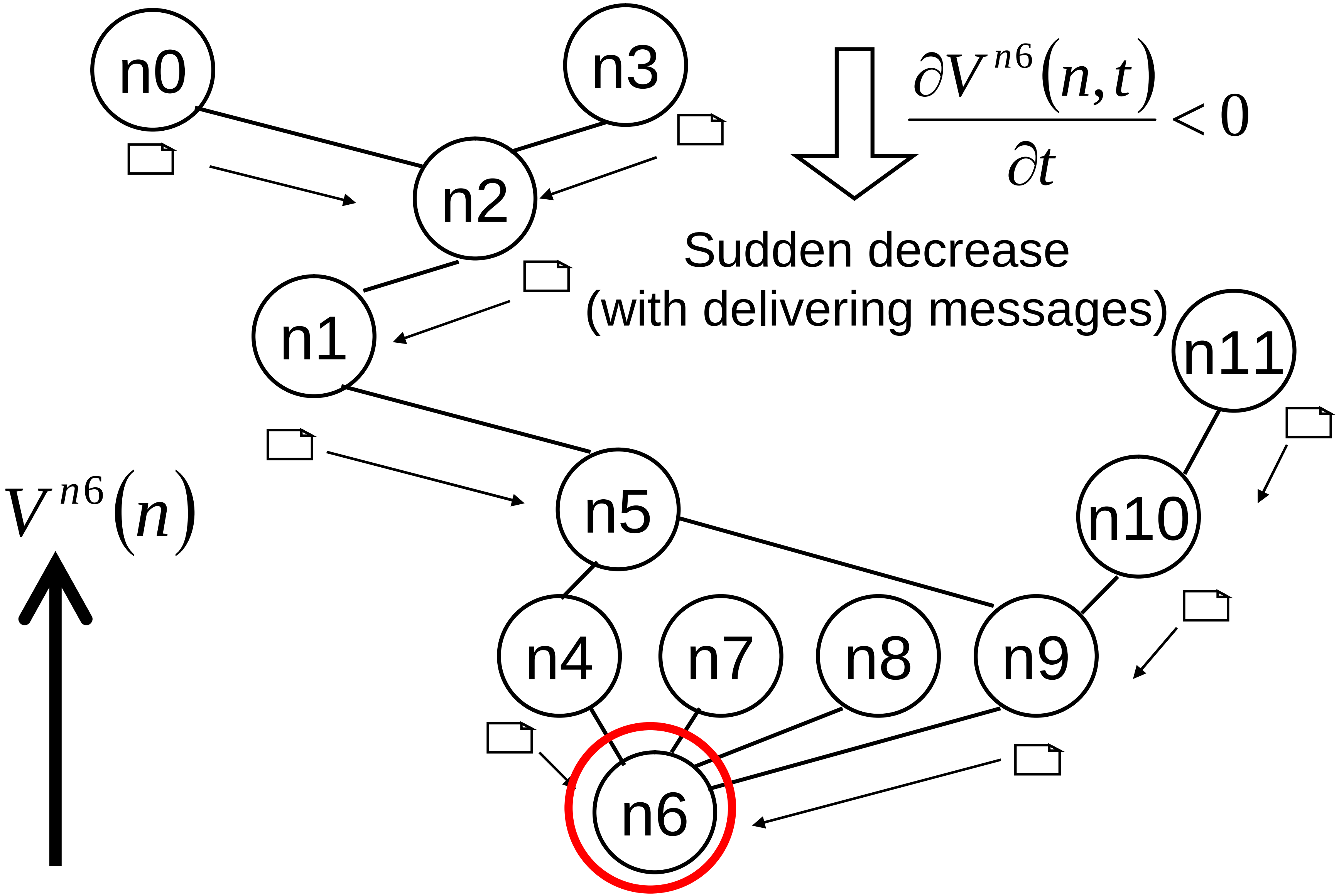


<< TCTR >>
Potential-Field Computation and Message Delivery (5/6)



When connected by another link

<< TCTR >>
Potential-Field Computation and Message Delivery (6/6)



Features of TCTR

- Routing without global knowledge of topology.
  - Potential-field computation

$$V^d(n,t+1) = V^d(n,t) + D \min_{k \in nbr(n)} \left\{ V^d(k,t) - V^d(n,t) \right\} + \rho$$

  - Message forwarding (i.e., next hop selection)

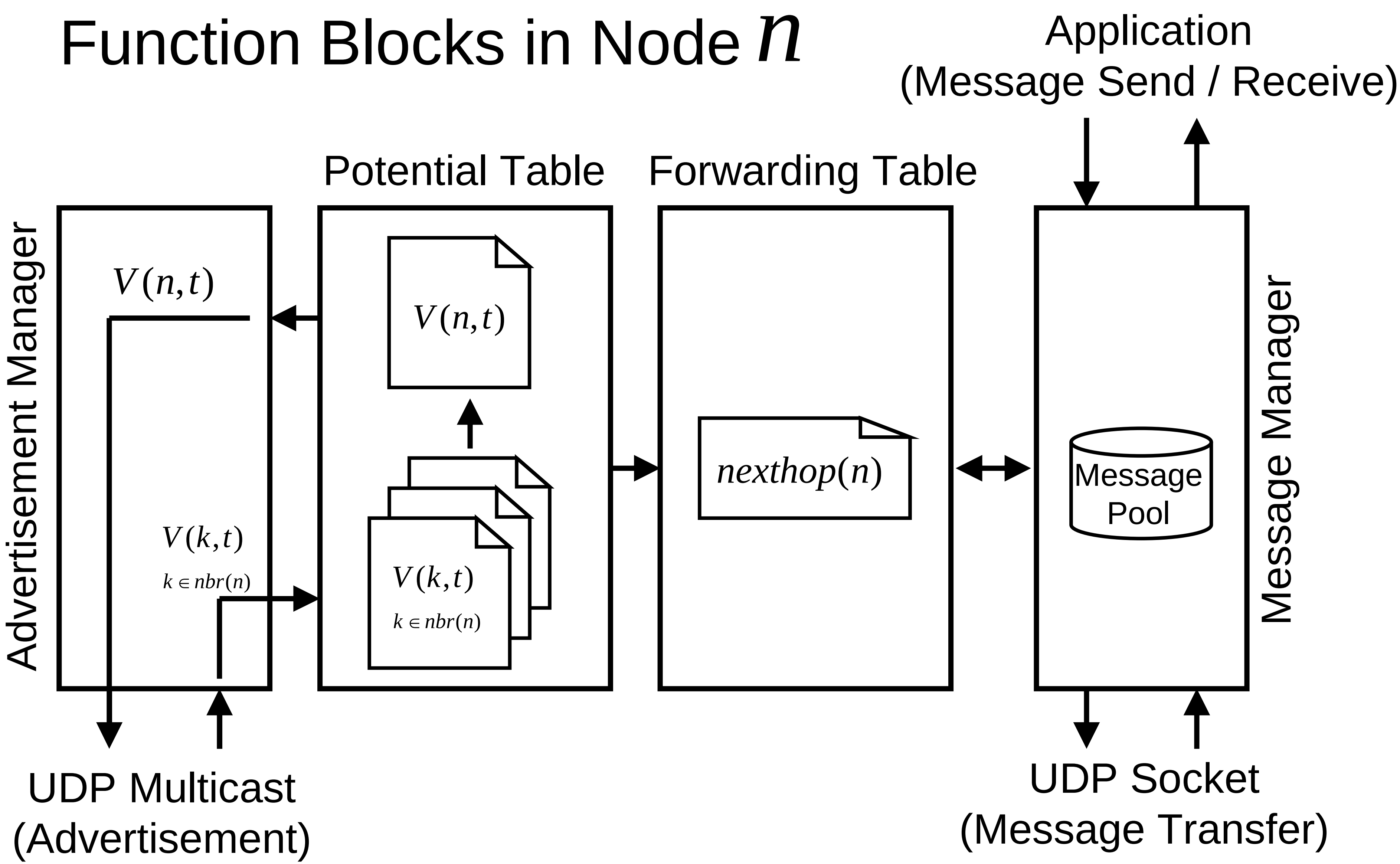
$$\left(\exists k \in nbr(n)\ F_k^d(n) \geq \alpha \right)$$
$$\rightarrow nexthop^d(n) = \left\{ k \mid F_k^d(n) = \max_{j \in nbr(n)} F_j^d(n) \right\}$$

- Message delivery is achieved totally relying on neighbor information.
- Thus, TCTR is tolerant for topology changes.

Outline

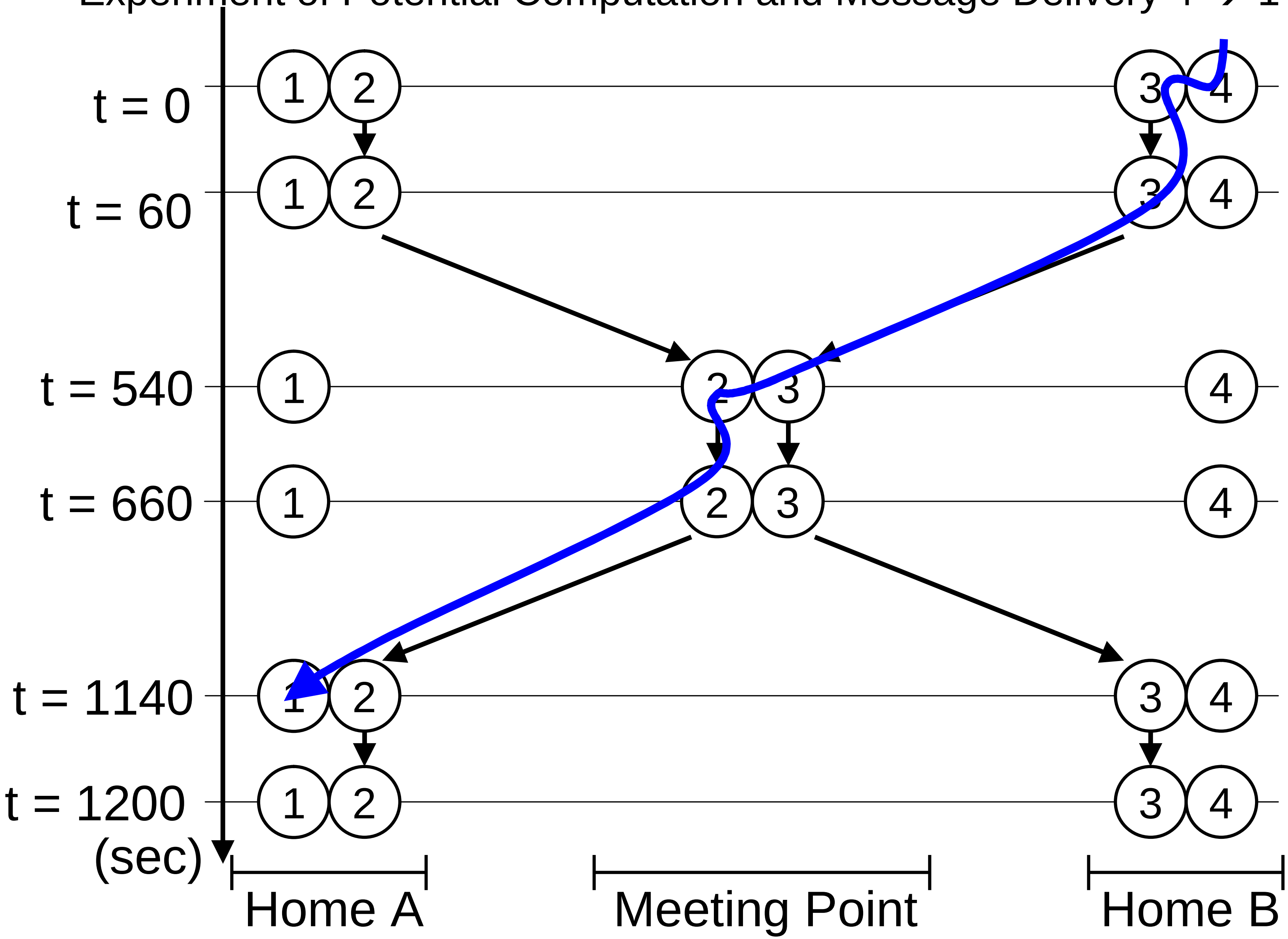
- Introduction
- Topology Change Tolerant Routing
  - Next hop selection and message forwarding
  - Potential-field computation
- Prototype Implementation
- Conclusion

Prototype Implementation

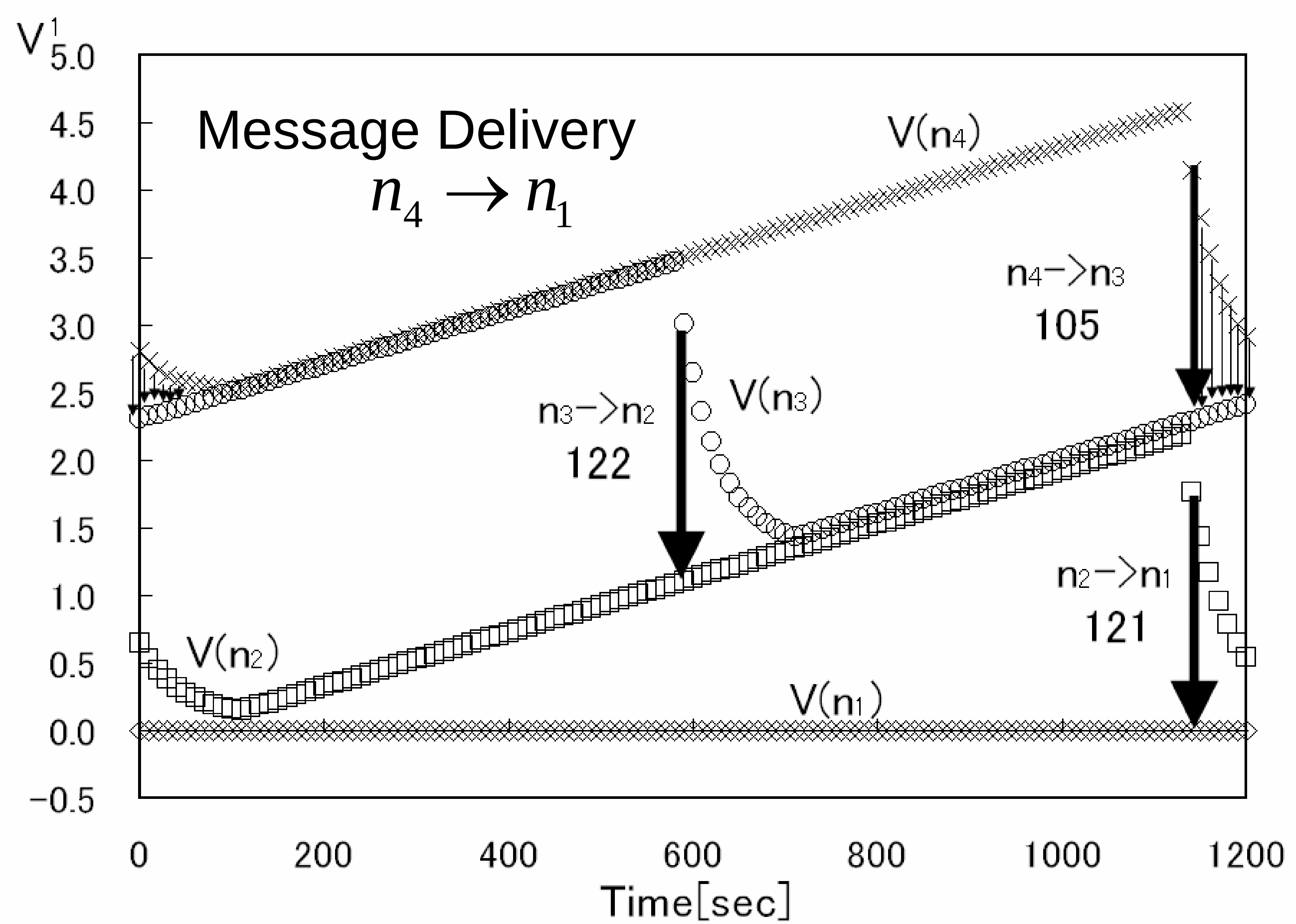


Message Delivery on Node Mobility

Experiment of Potential Computation and Message Delivery 4 → 1



Potential Computation & Message Delivery



Outline

- Introduction
- Topology Change Tolerant Routing
  - Next hop selection and message forwarding
  - Potential-field computation
- Prototype Implementation
- Conclusion

Conclusion

- TCTR is tolerant for topology changes
  - Routing without global knowledge of topology.
  - Routing uses only neighbor status.
- Potential-field computation

$$V^d(n,t+1) = V^d(n,t) + D \min_{k \in nbr(n)} \left\{ V^d(k,t) - V^d(n,t) \right\} + \rho$$

- Future work
  - Various mobility pattern
  - Multiple replica cases