Energy-Efficient TDMA Schedules for Data-Gathering in Wireless Sensor Networks

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June 25th 2008

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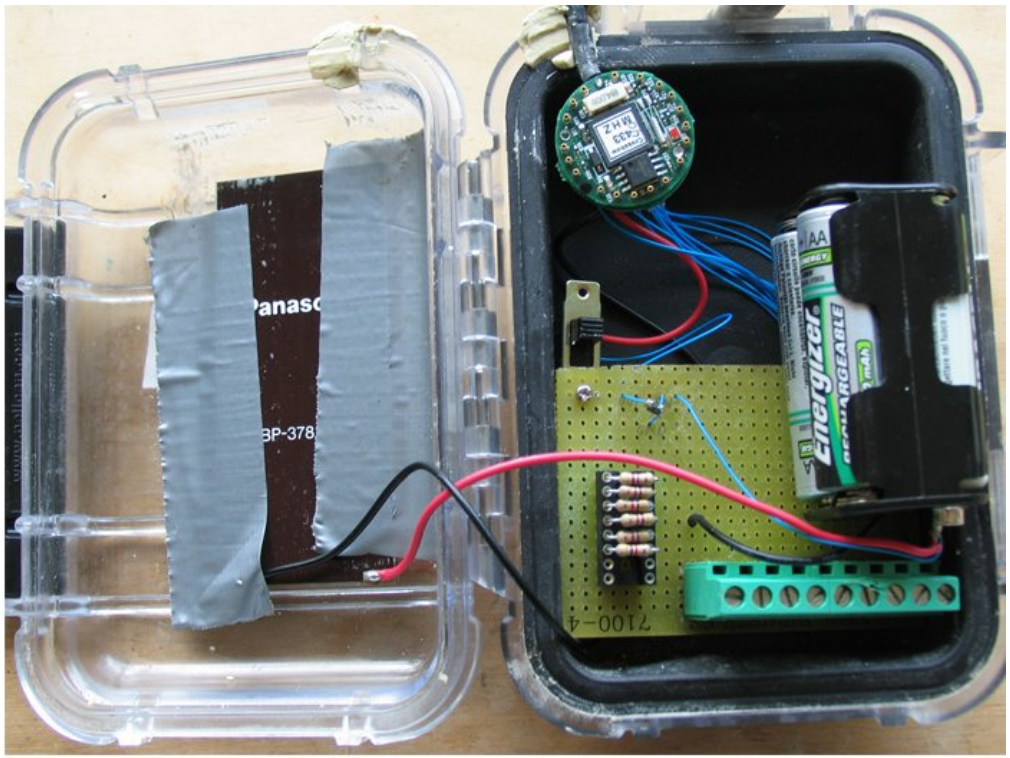
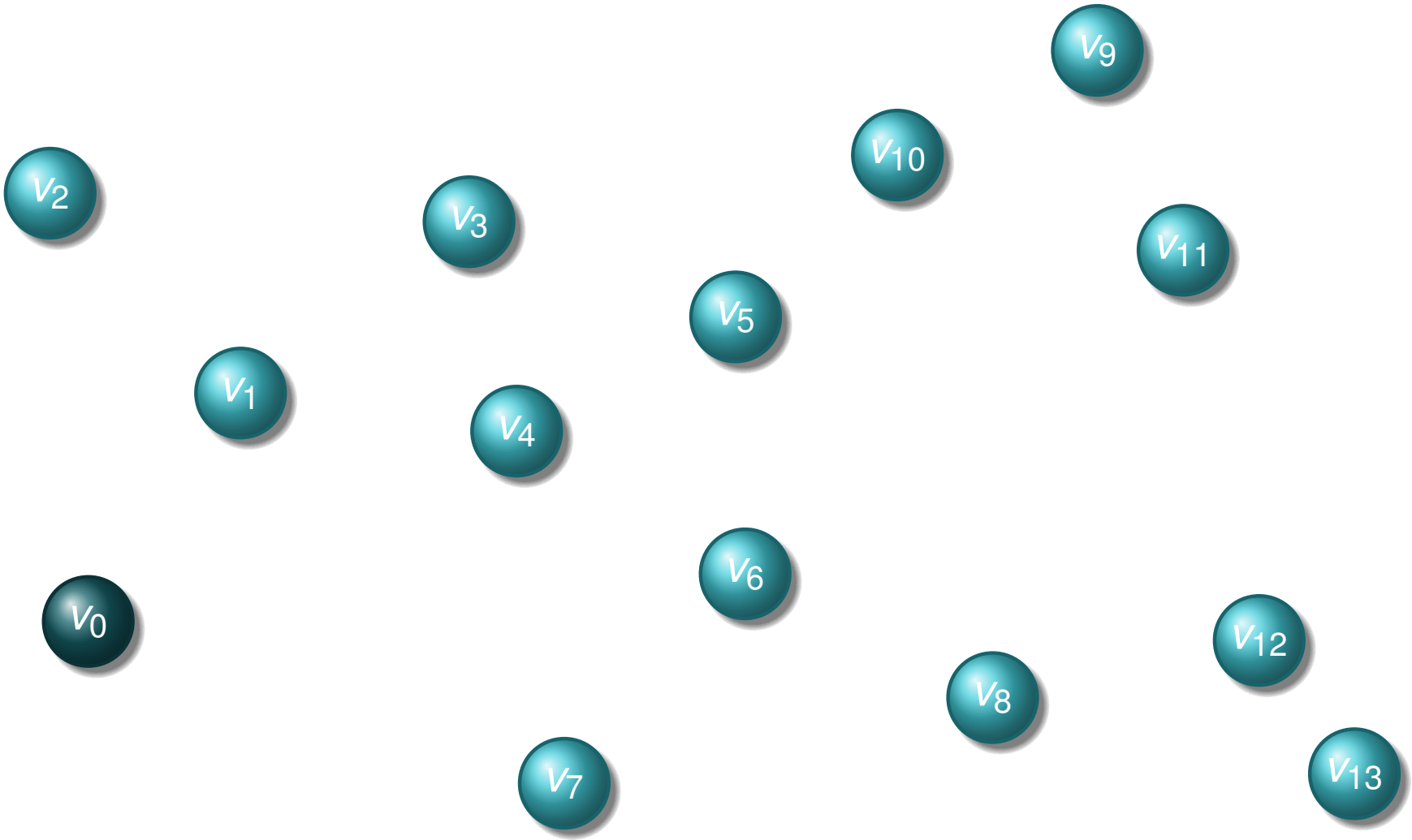
Wireless Sensor Networks



Source: http://camalie.com/WirelessSensing/WirelessSensors.htm

Data-Gathering in Wireless Sensor Networks



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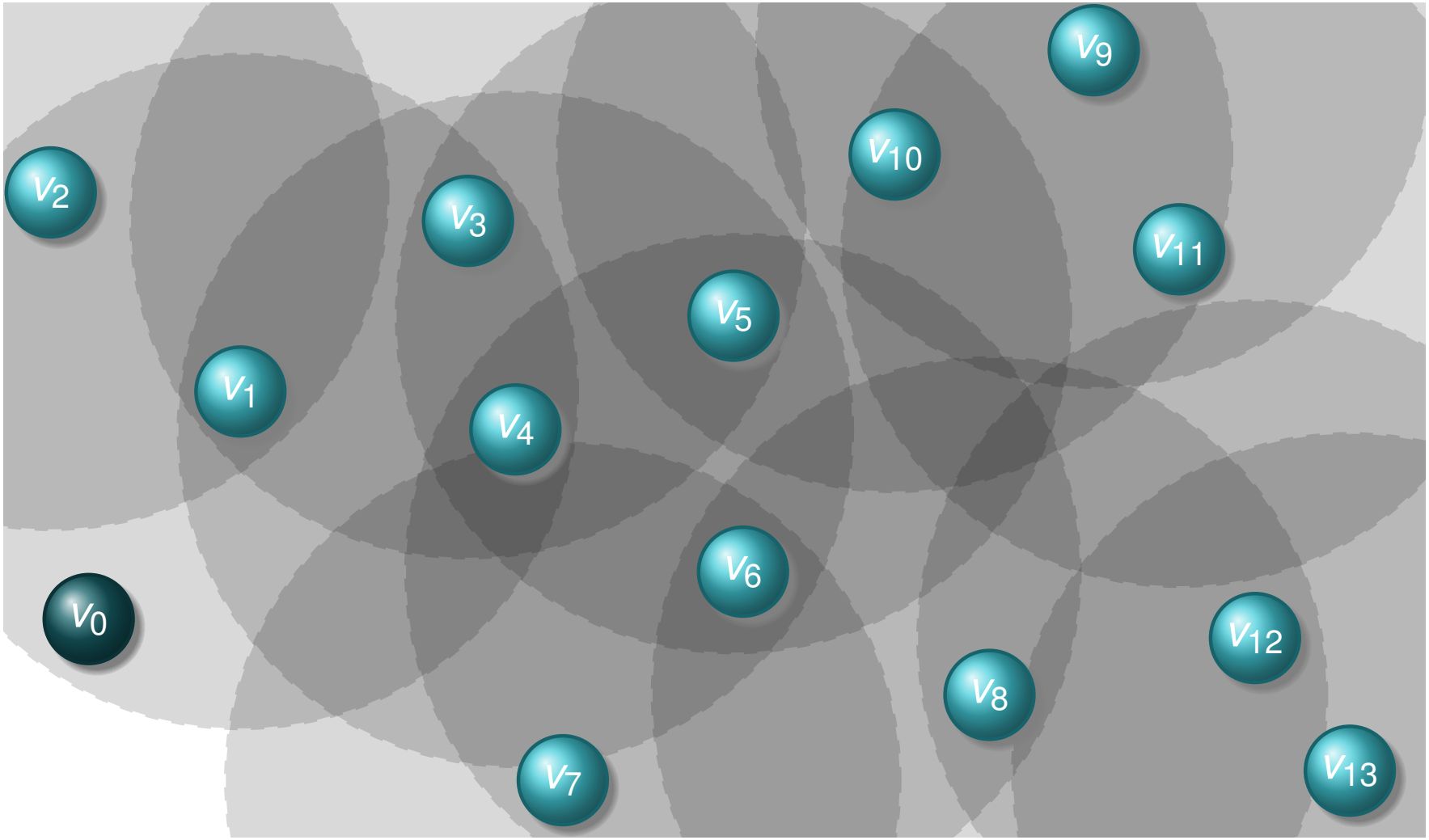

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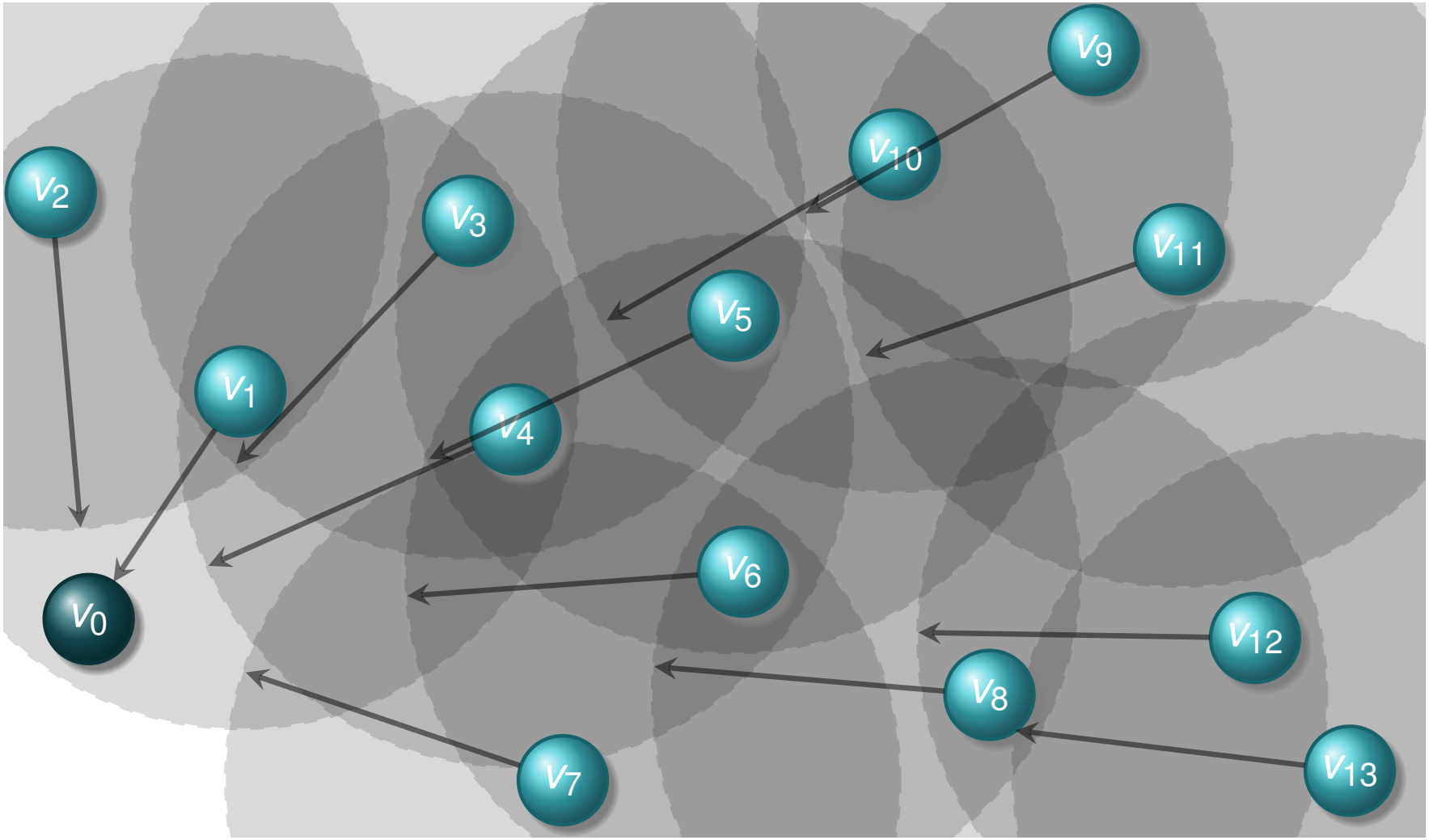

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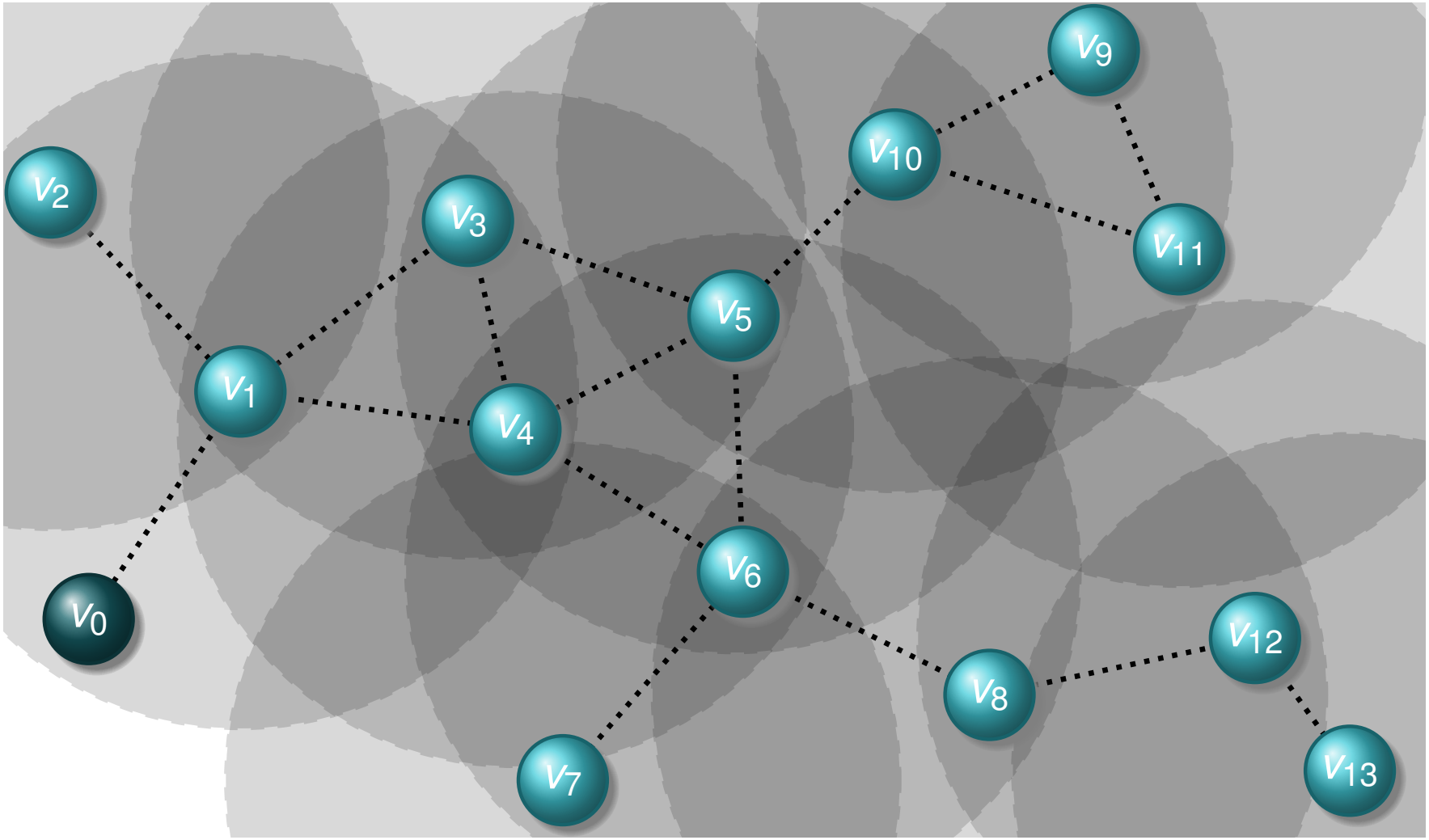

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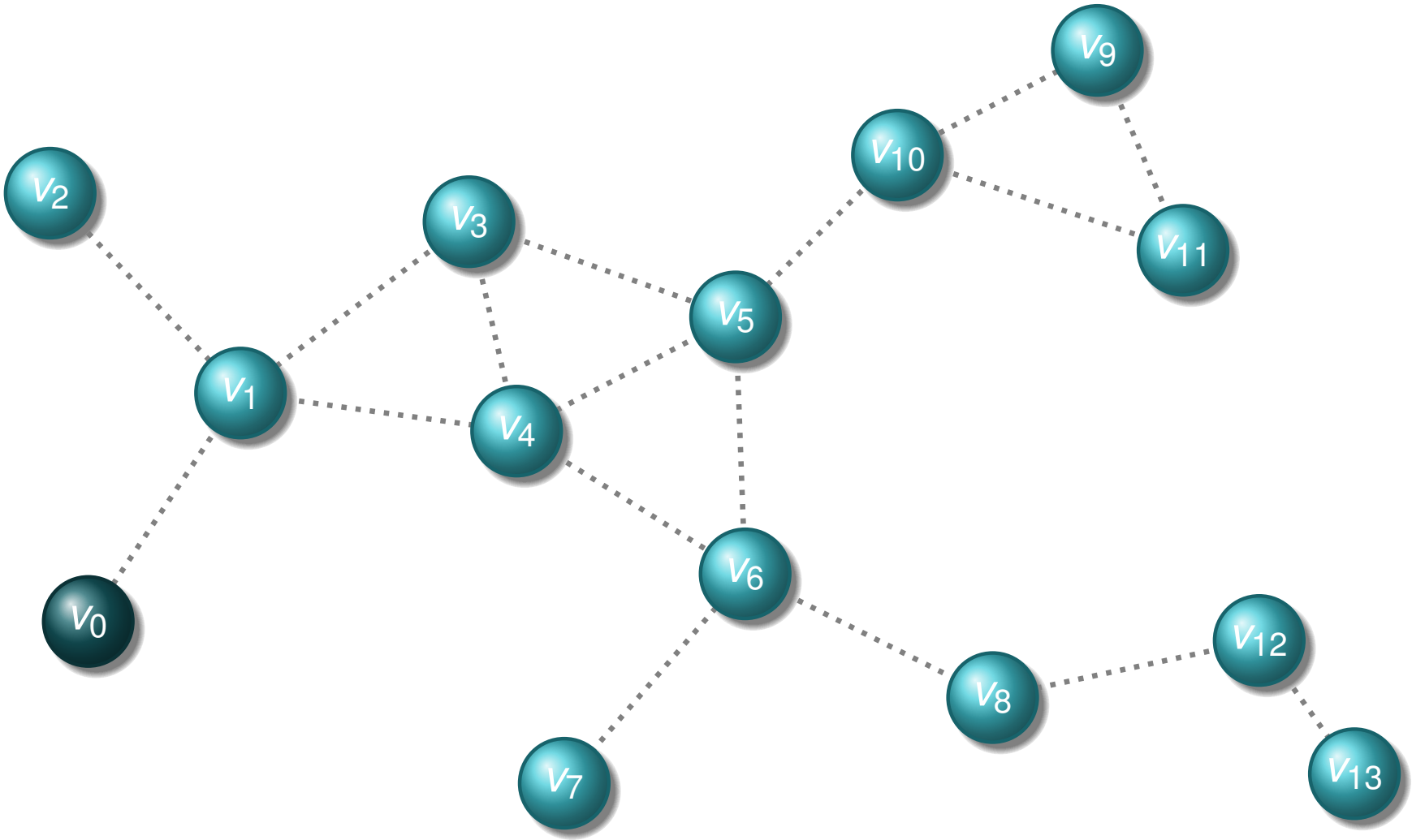

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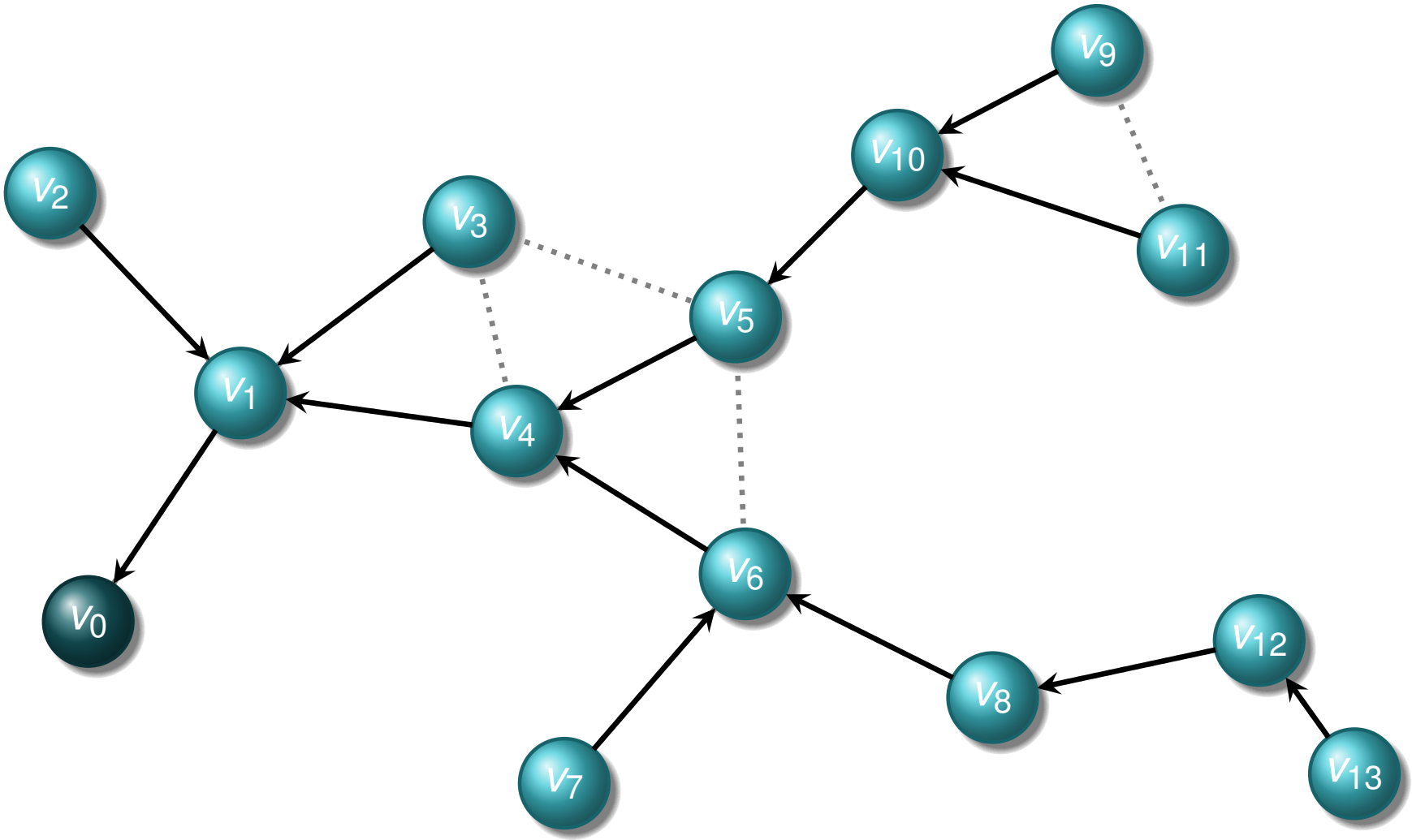

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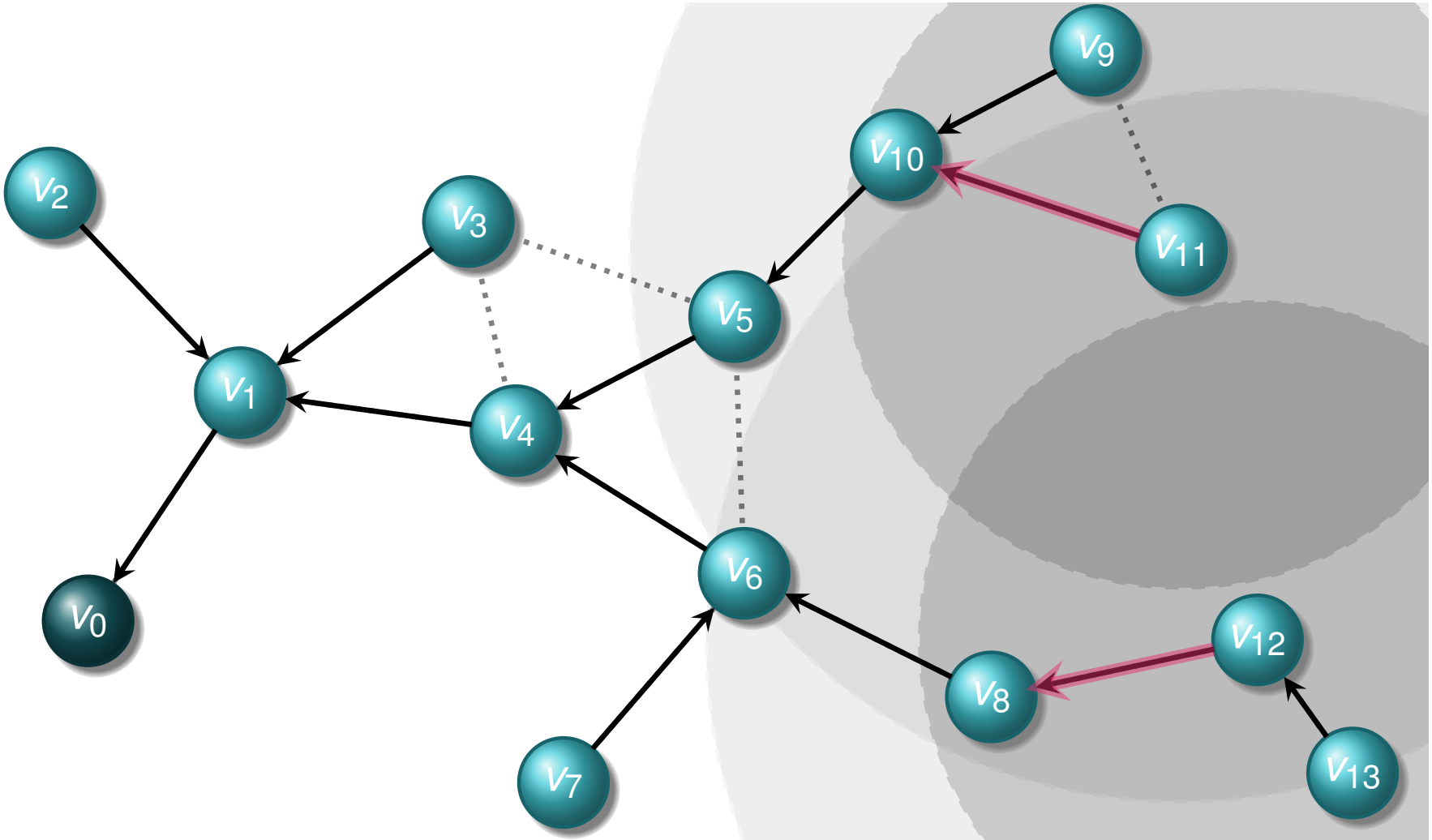

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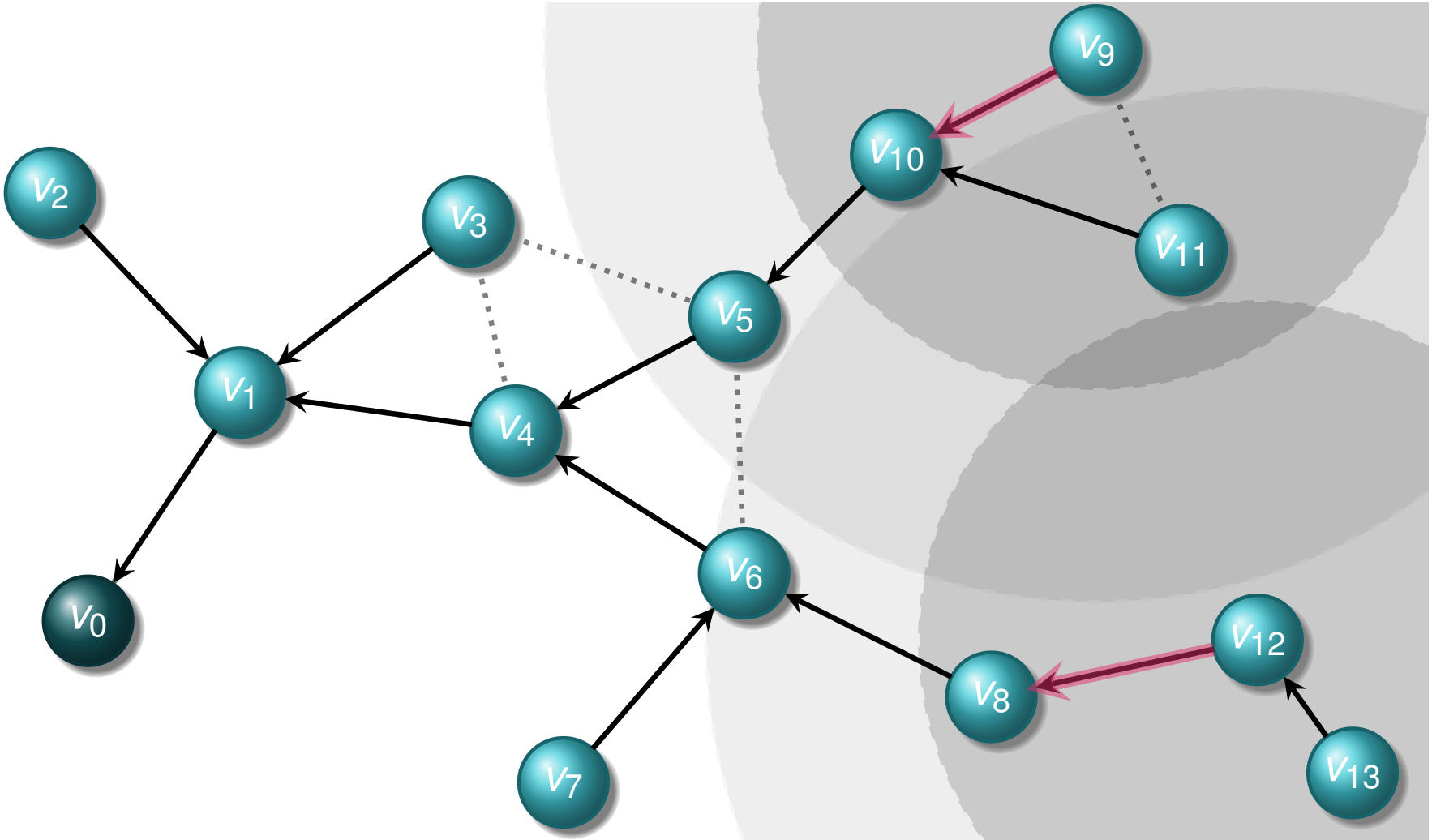

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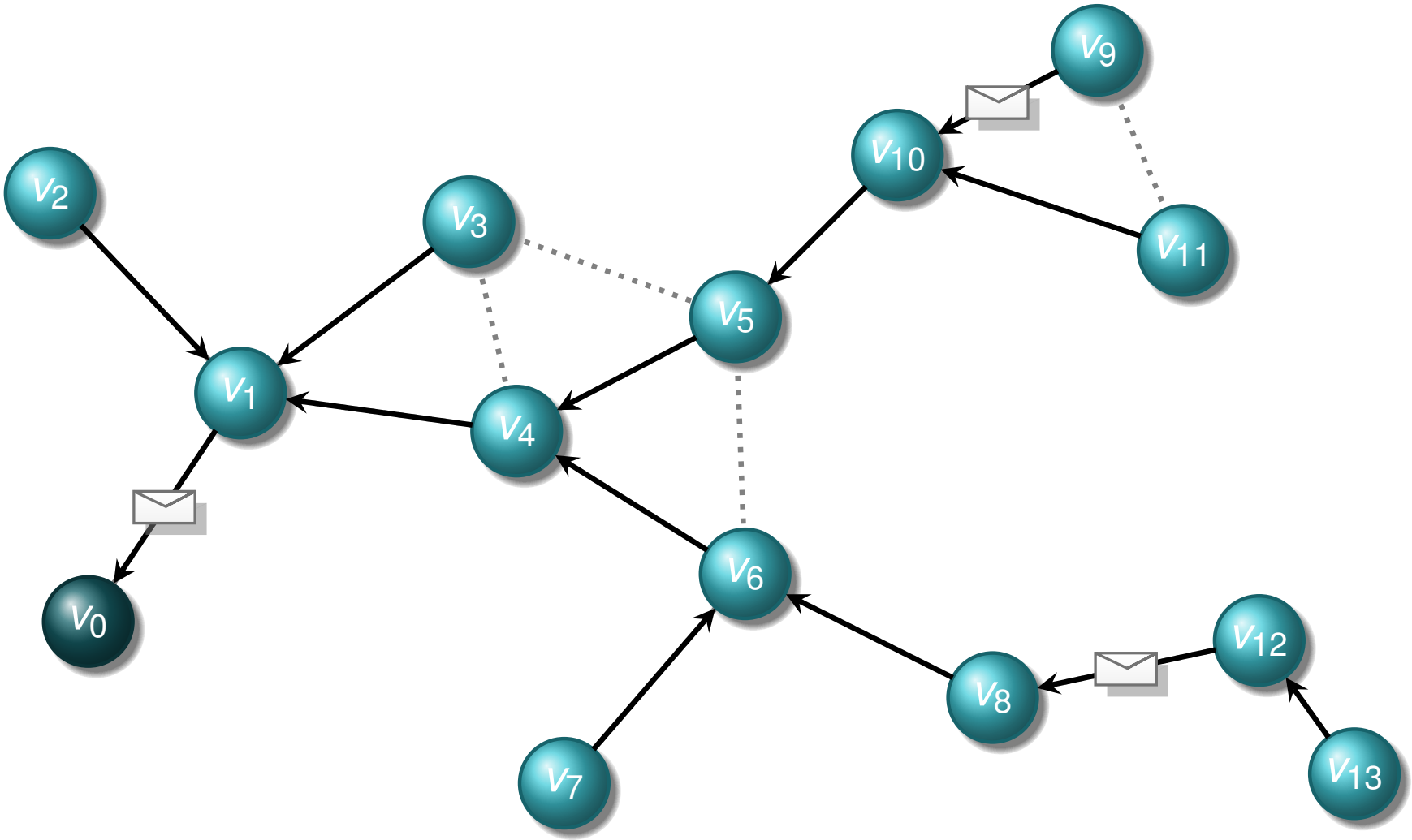

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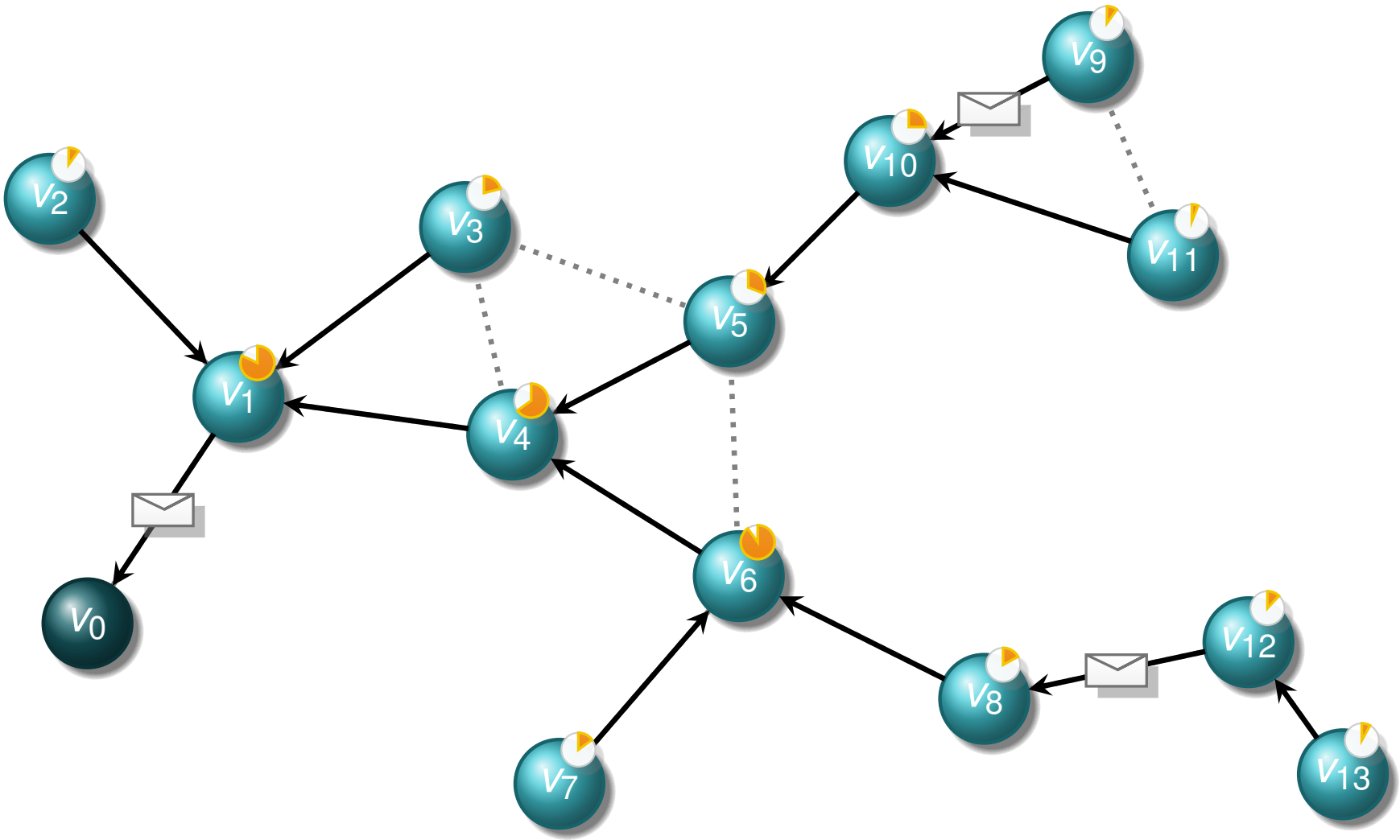

Scenario

- Data-Gathering
- One sink
- Two-phase strategy
- Routing tree
- Reliable transportation
  - Hop-to-hop Acknowledgments
  - Buffer Management / Flow Control
- Scheduled transmission

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- Data-Gathering
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Which schedule is the best?

Scheduling

	Scheduled CSMA	TDMA
Overhearing	$\ominus$	$\oplus$ / $\oplus\oplus$
Idle Listening	$\ominus$	$\oplus$ / $\oplus\oplus$
Collisions	$\ominus$	$\oplus$
Protocol Overhead	$\odot$	$\ominus$
Adaptivity	$\odot$	$\odot$

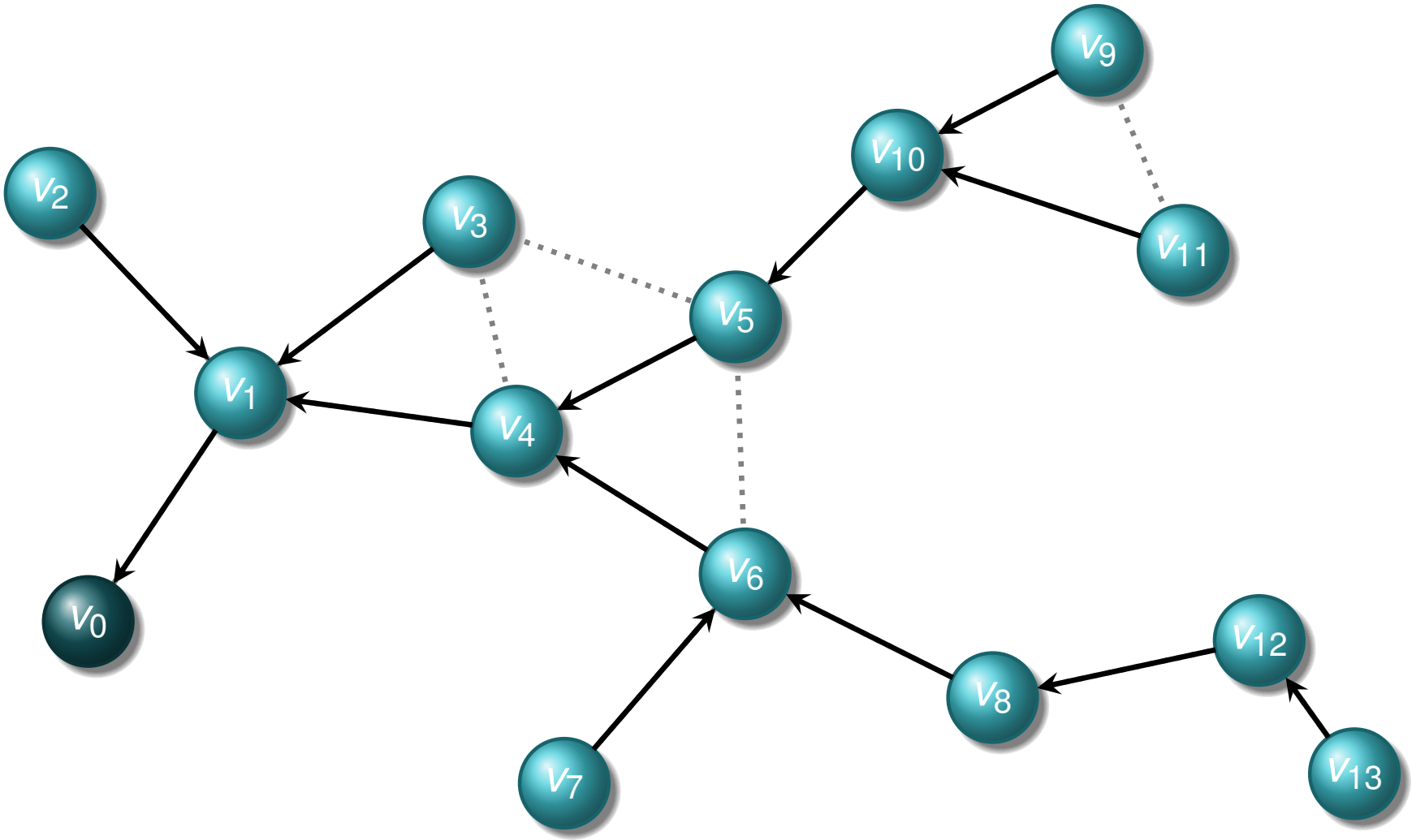
Objectives of This Thesis

- Analytical investigation of existing TDMA schedules
- Design of a new TDMA schedule
- Development of a ns-2 simulation framework
- In-depth comparison of the schedules via simulation

Types of TDMA Schedules

- **Type I**
  - Less slots than nodes
  - Graph coloring
  - Spatial reuse
- **Type II**
  - As many slots as nodes
  - One slot for each node
  - Temporal reuse
- **Type III**
  - More slots than nodes
  - One slot for each child plus one for sending a local packet
  - No reuse

Type I Slot Assignment (3-hop)



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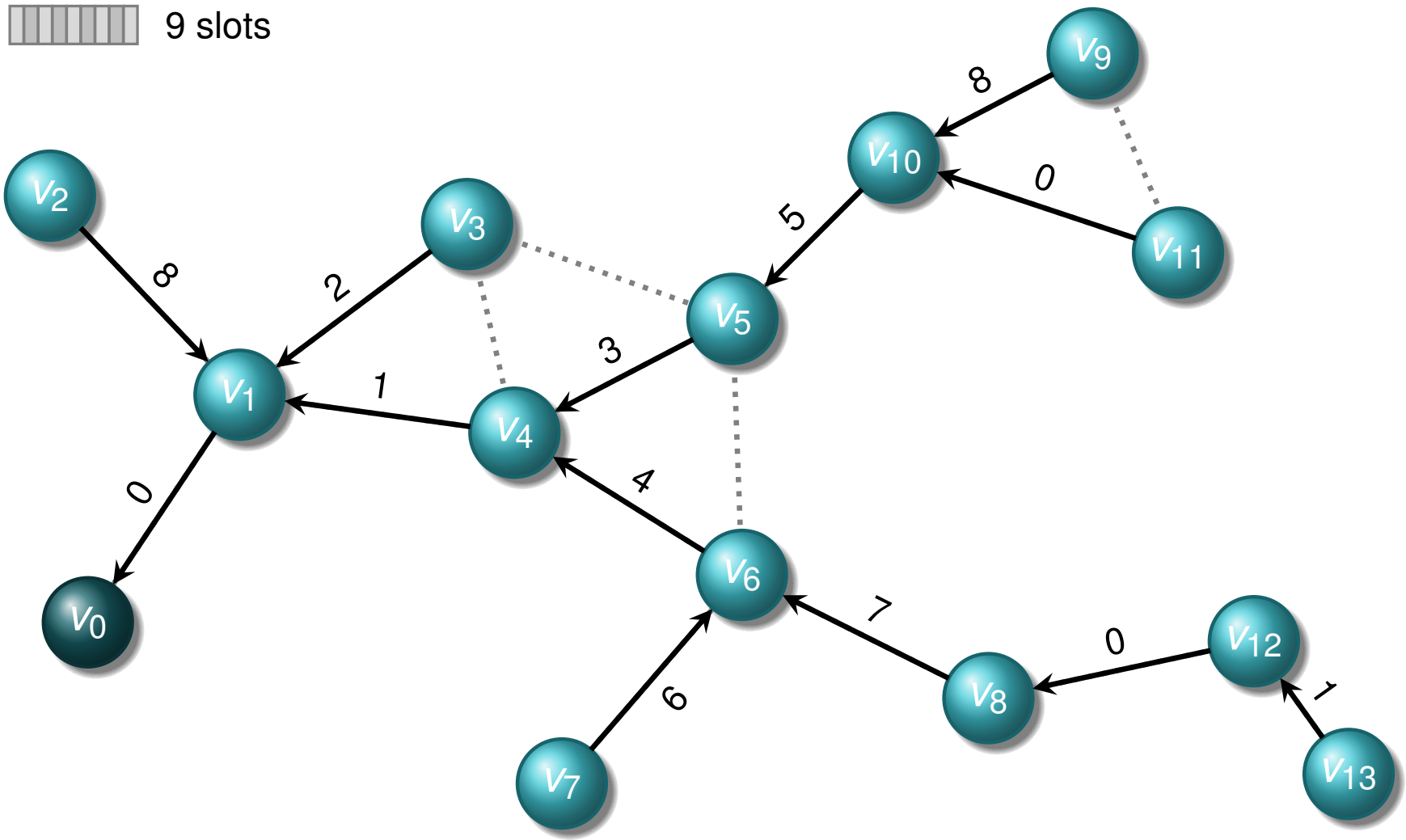

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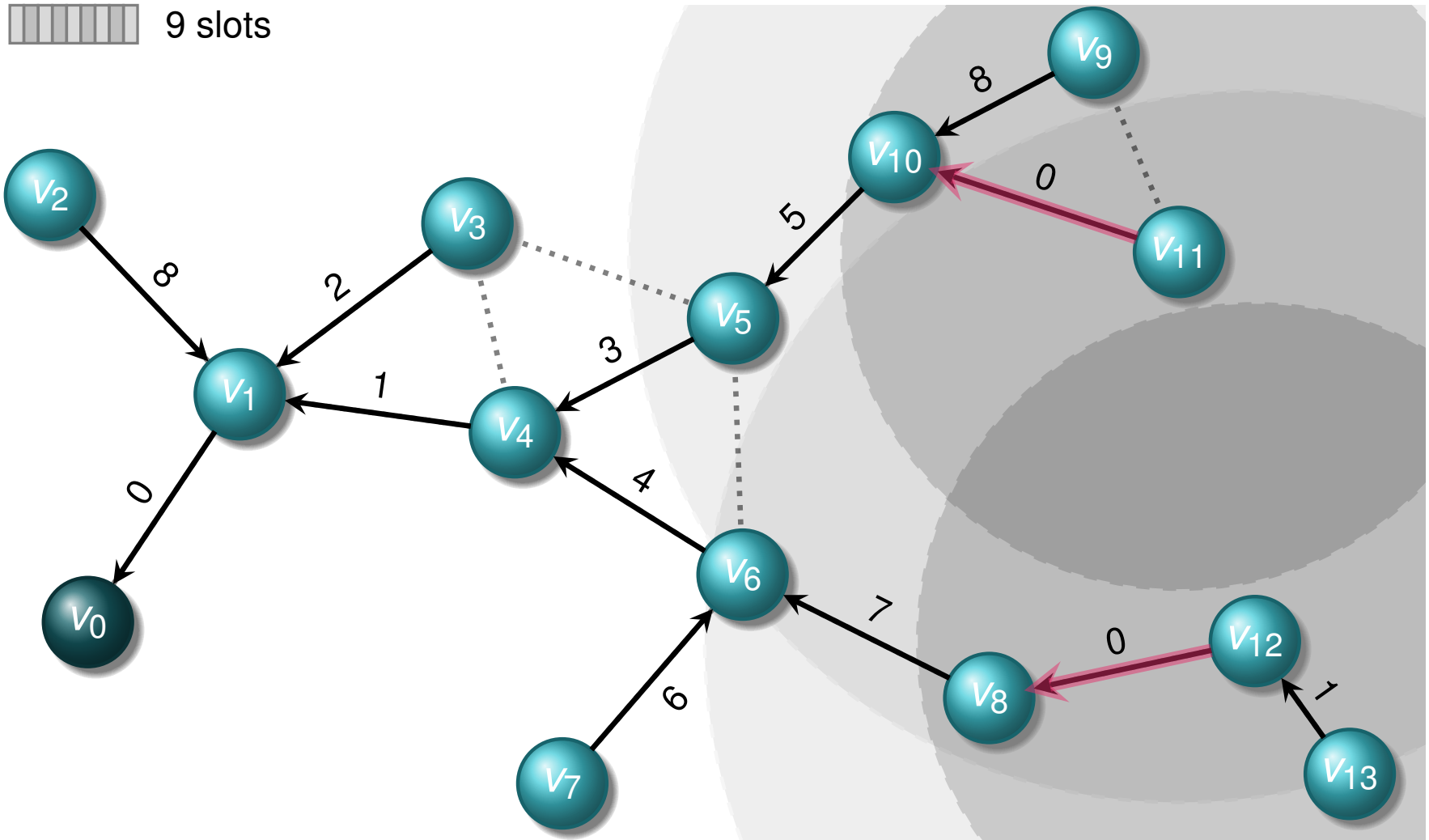

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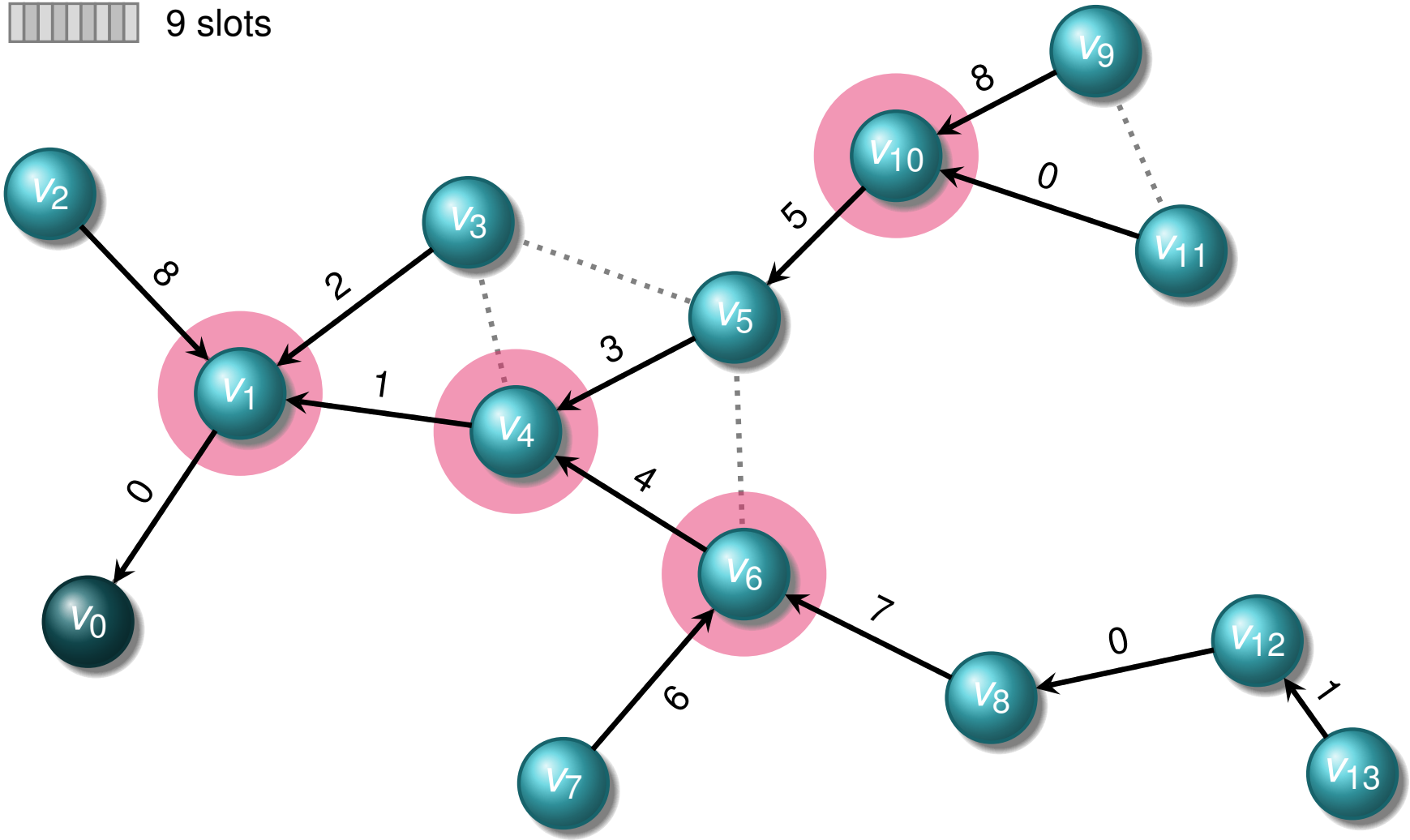
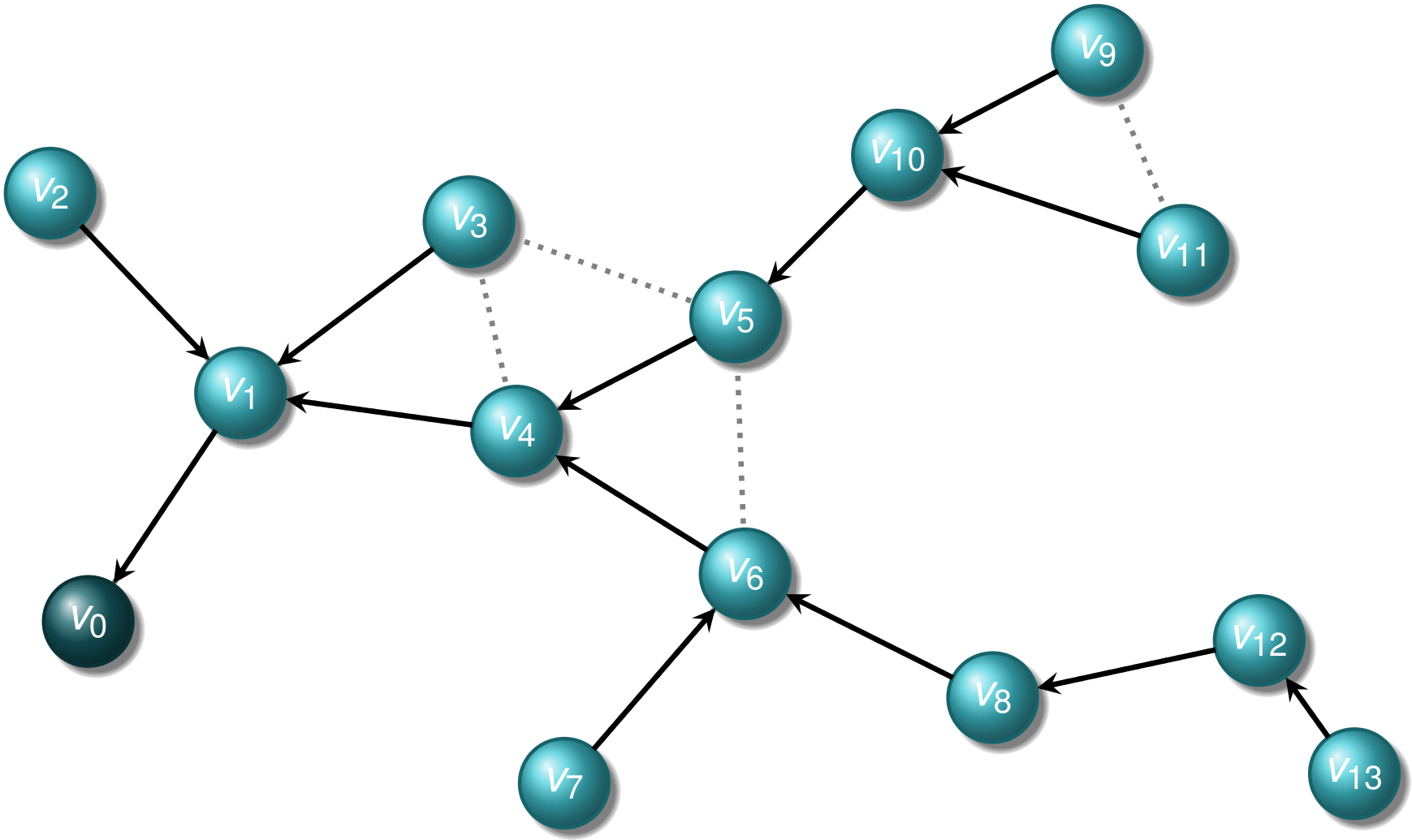


Type II Slot Assignment



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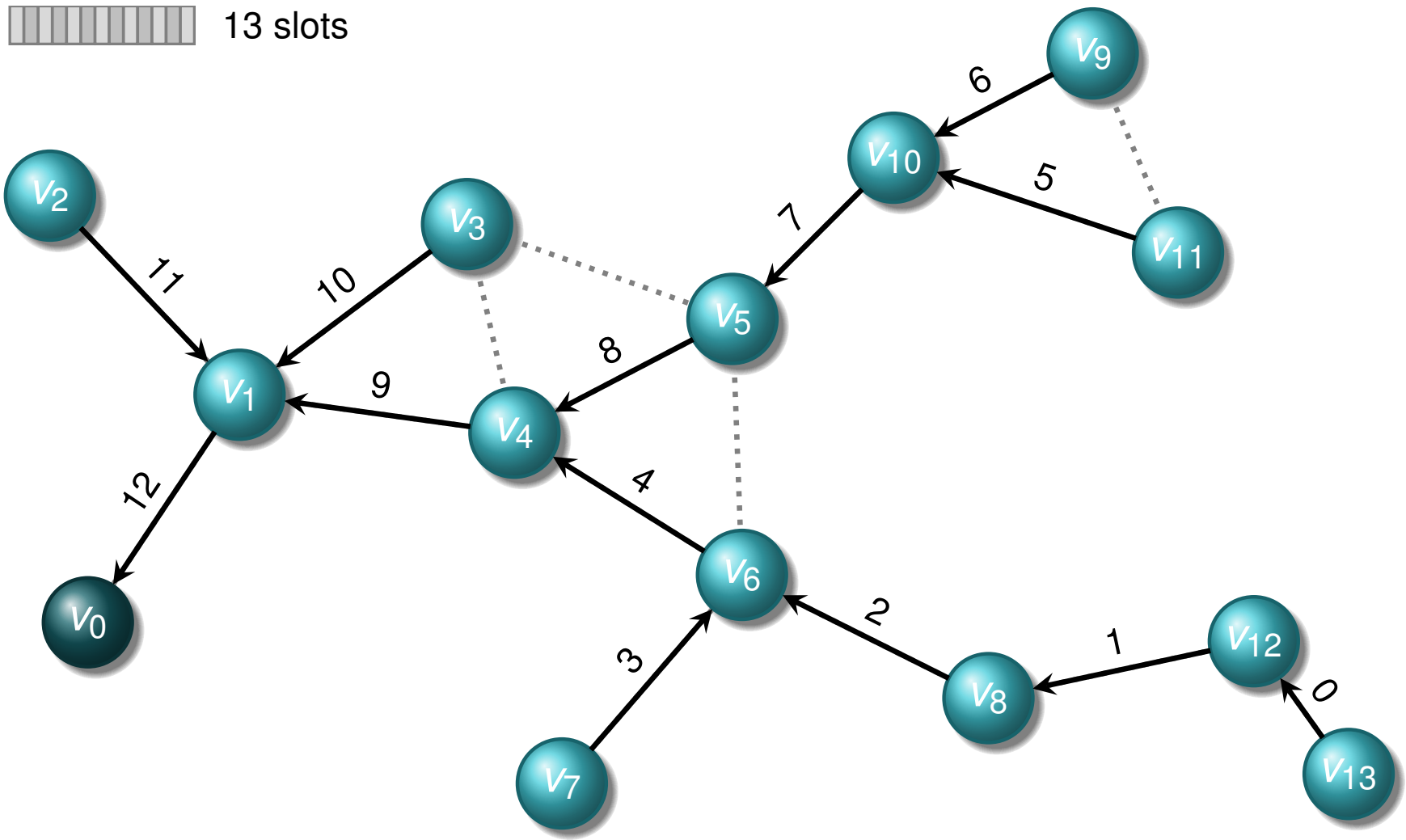

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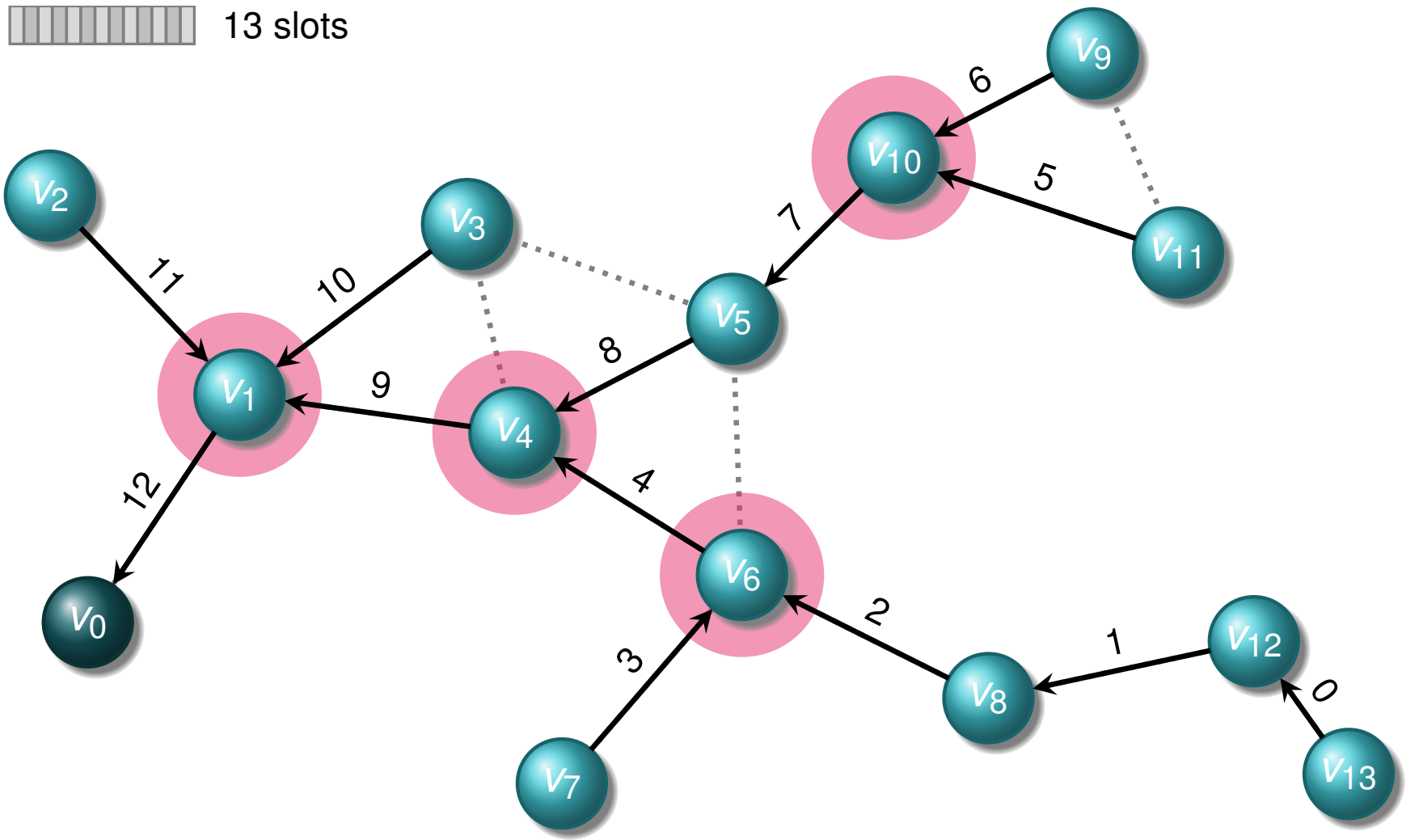

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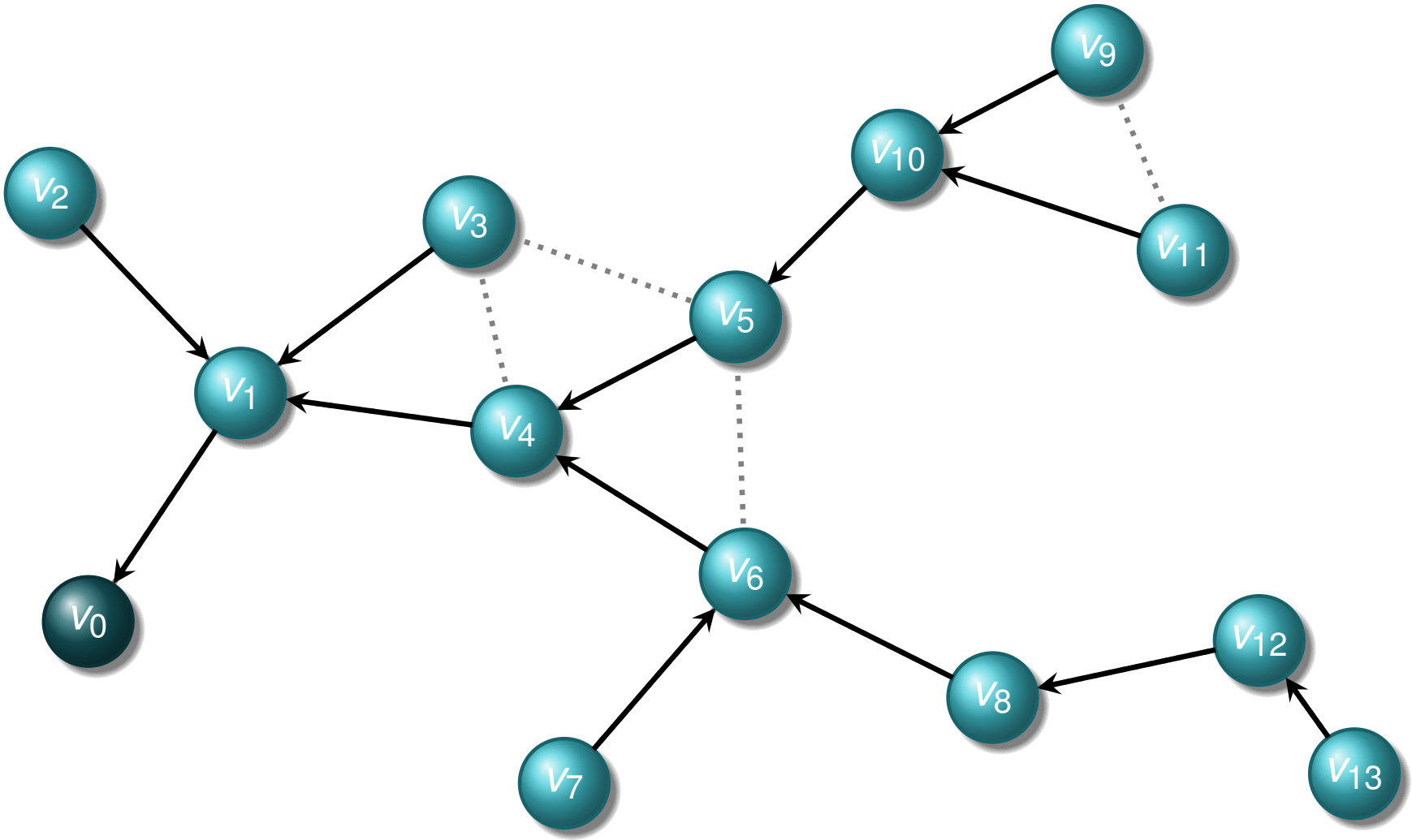

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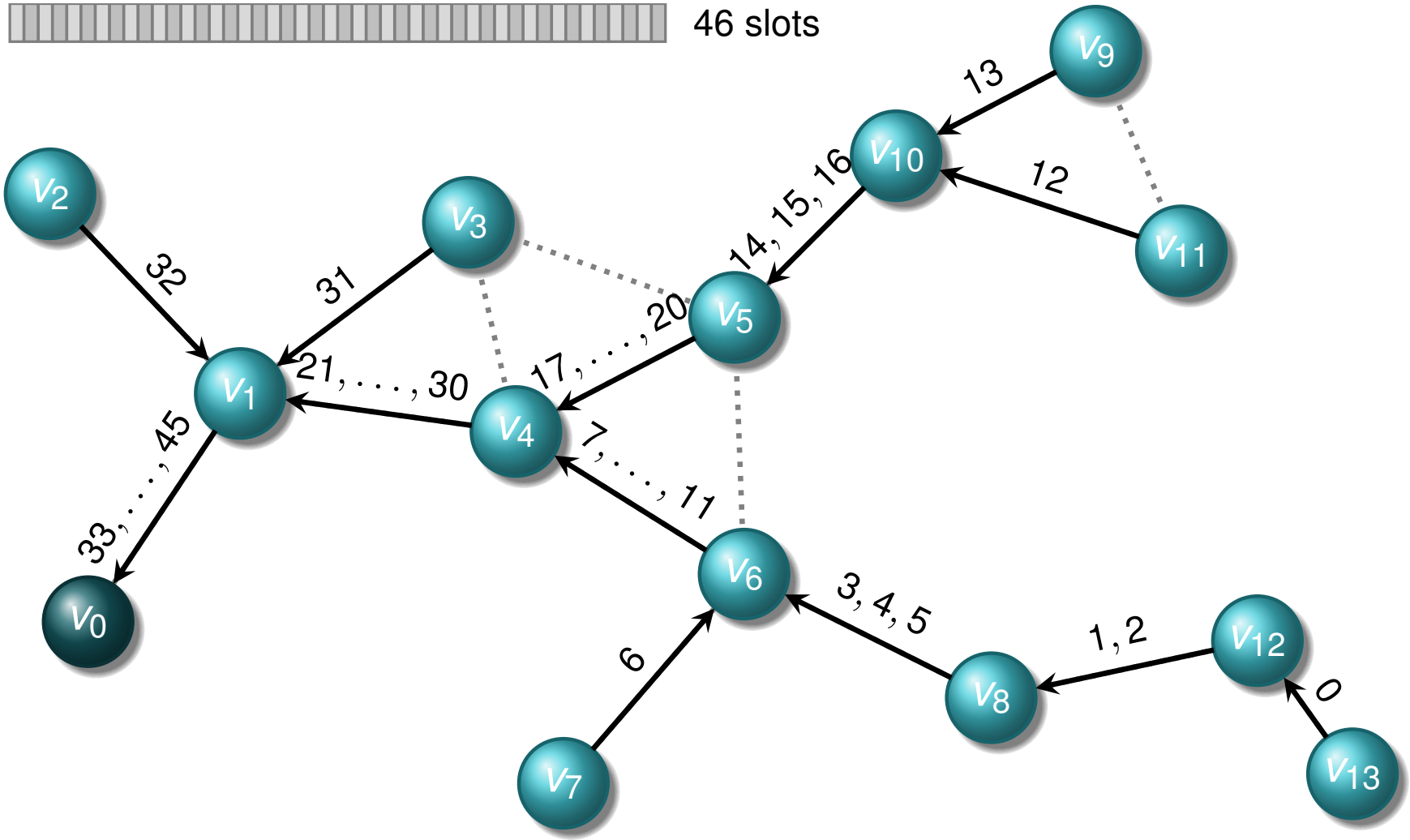

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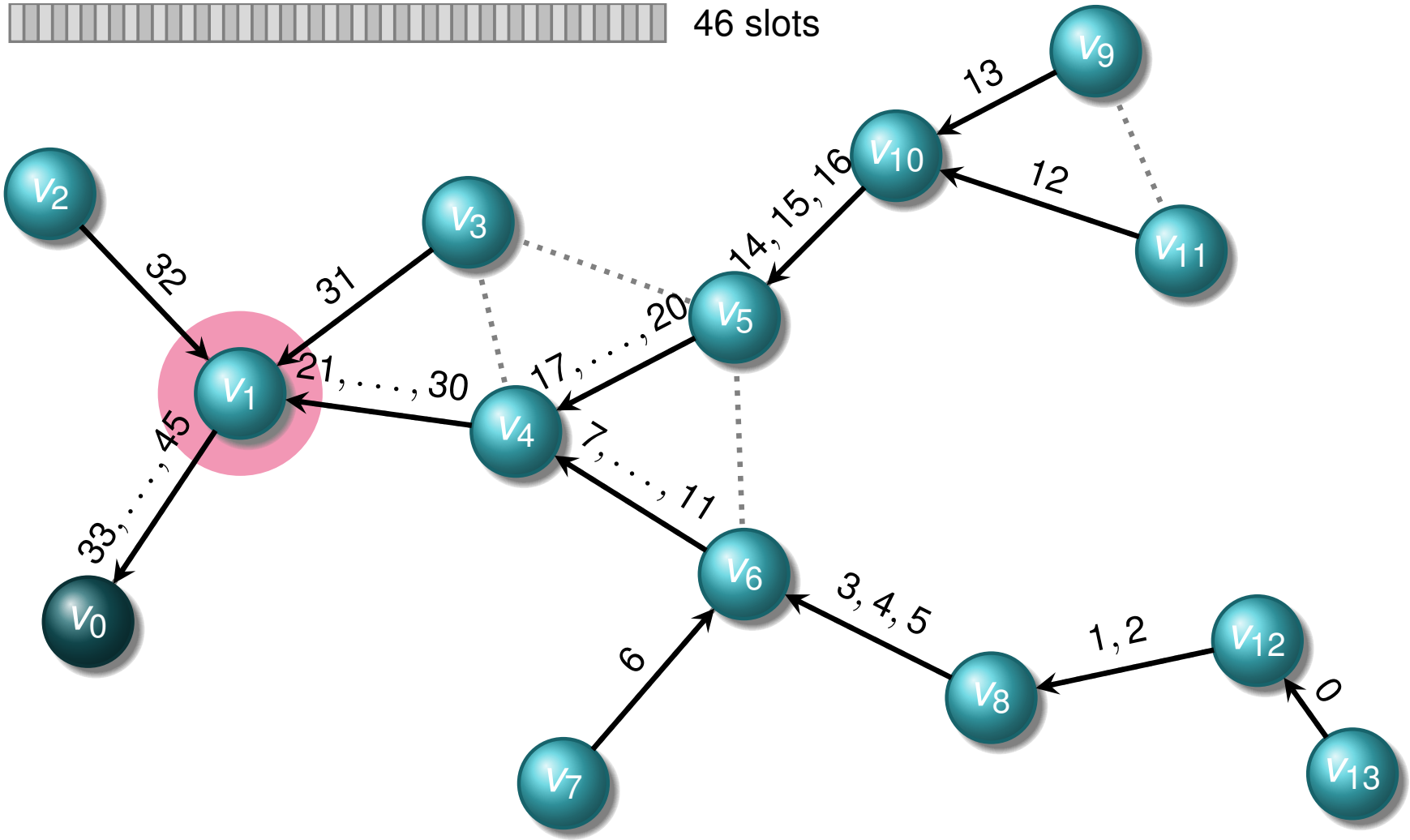


Analysis

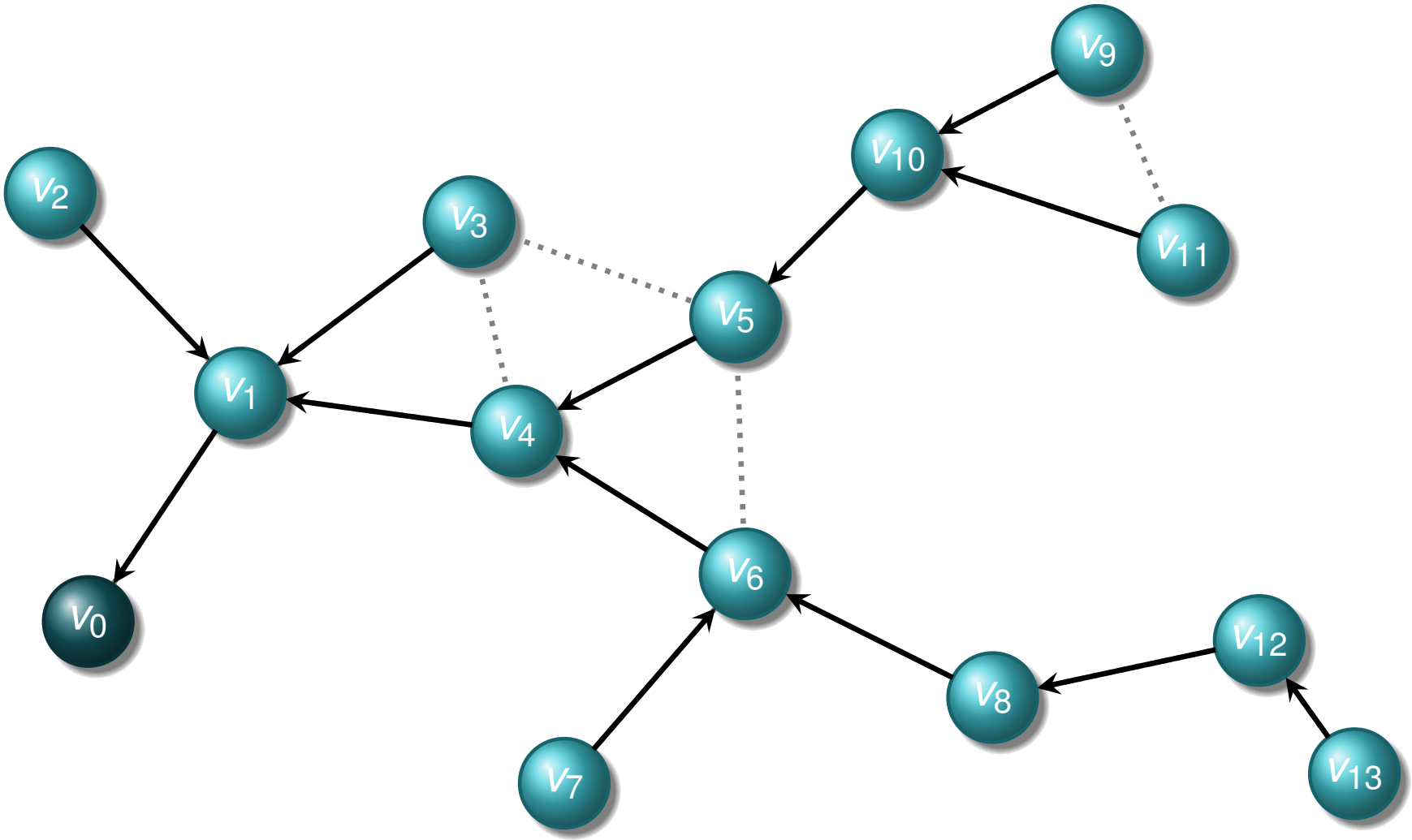
	Type I	Type II	Type III
Collisions	✓	–	–
Buffer congestion	✓	✓	(✓)
High memory consumption	–	✓	–
Large number of slots	–	–	✓

Spatial Path-Based Reuse (SPR)

Design Goals

- Balanced number of slots for receiving and sending
  $\Rightarrow$ no buffer congestion
- Reuse slots after κ hops on paths from a leaf to the sink
  $\Rightarrow$ no inter-path collisions
- Facile slot assignment and small memory footprint
  $\Rightarrow$ low overhead and applicability in large networks

SPR Slot Assignment, $\kappa = 4$



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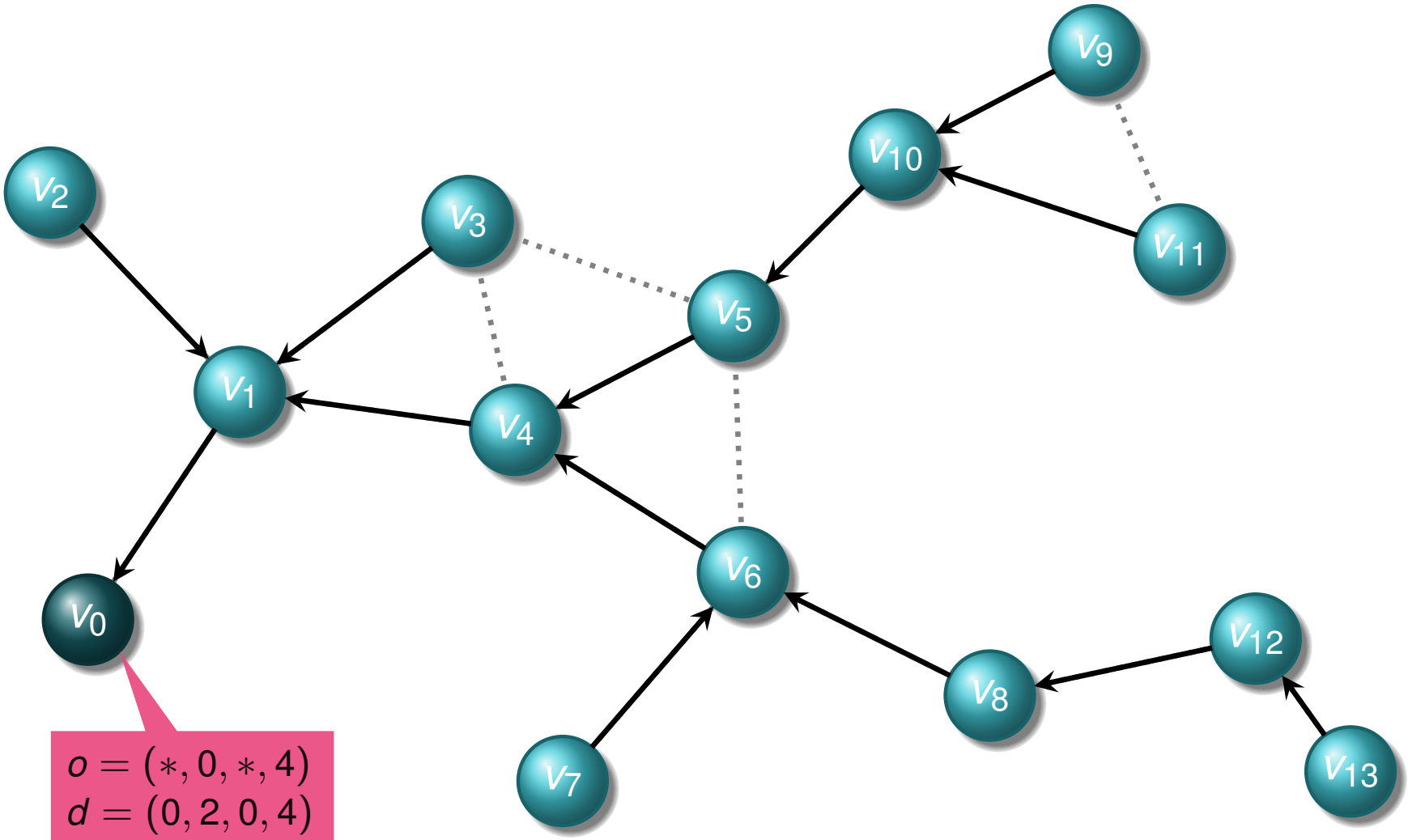

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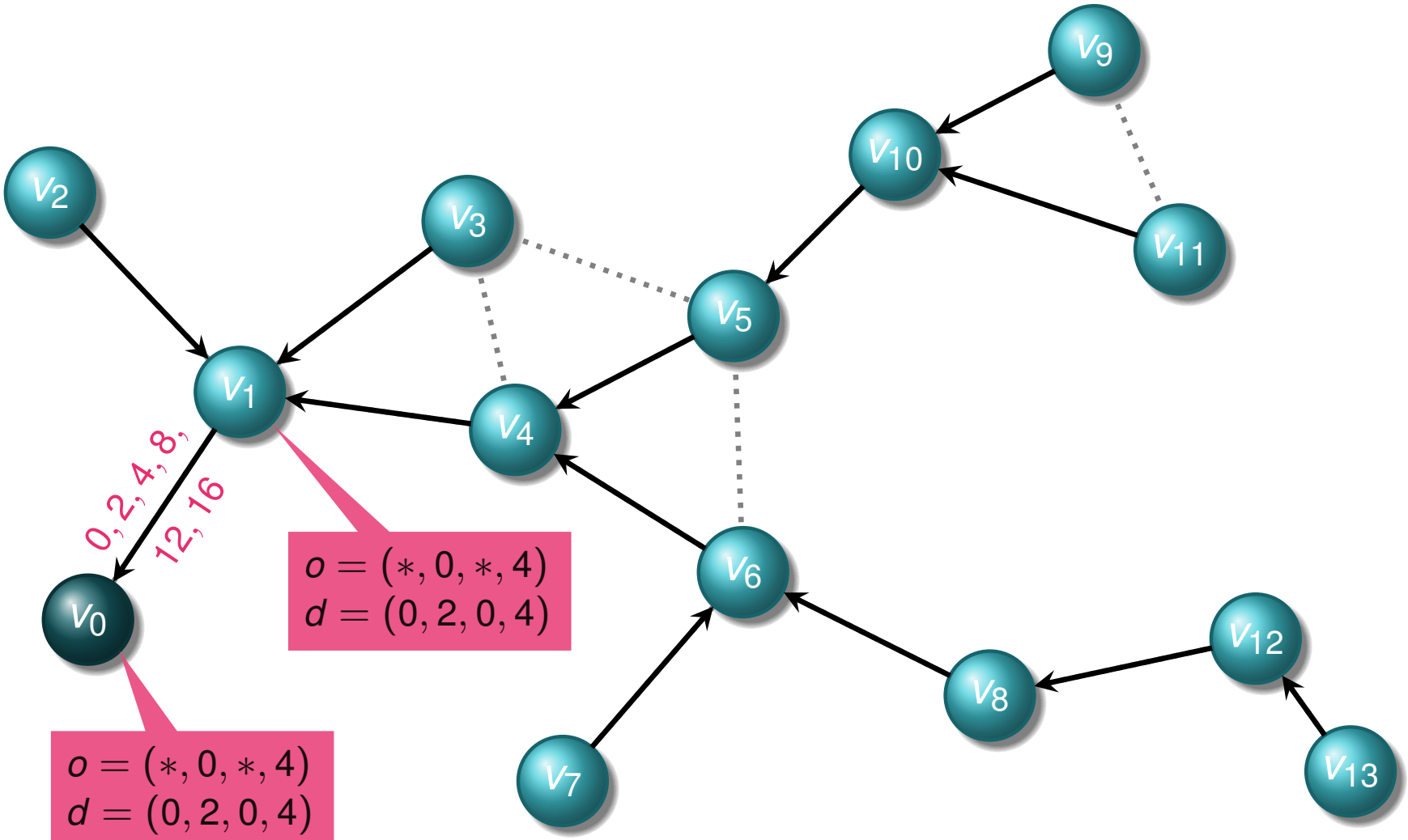

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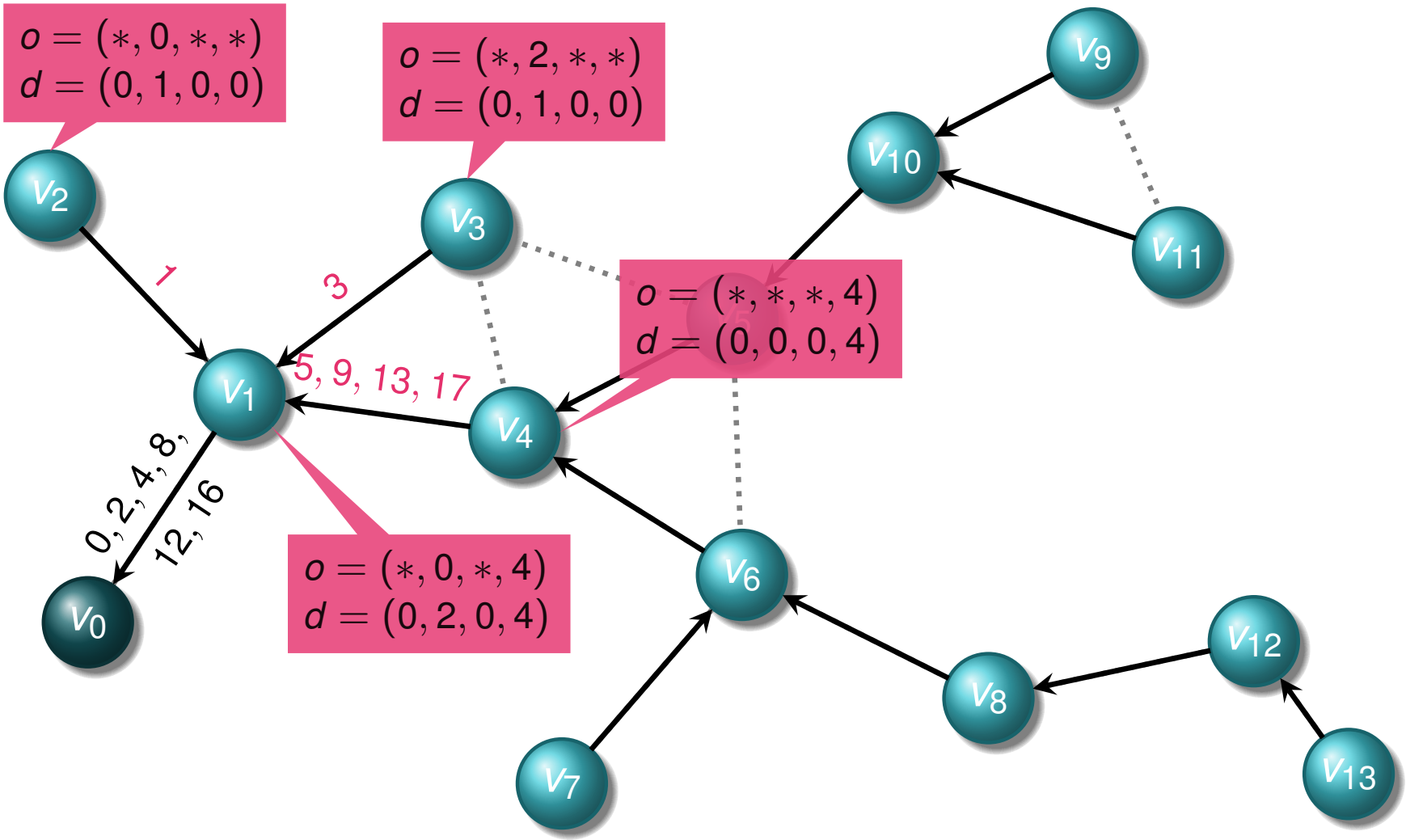

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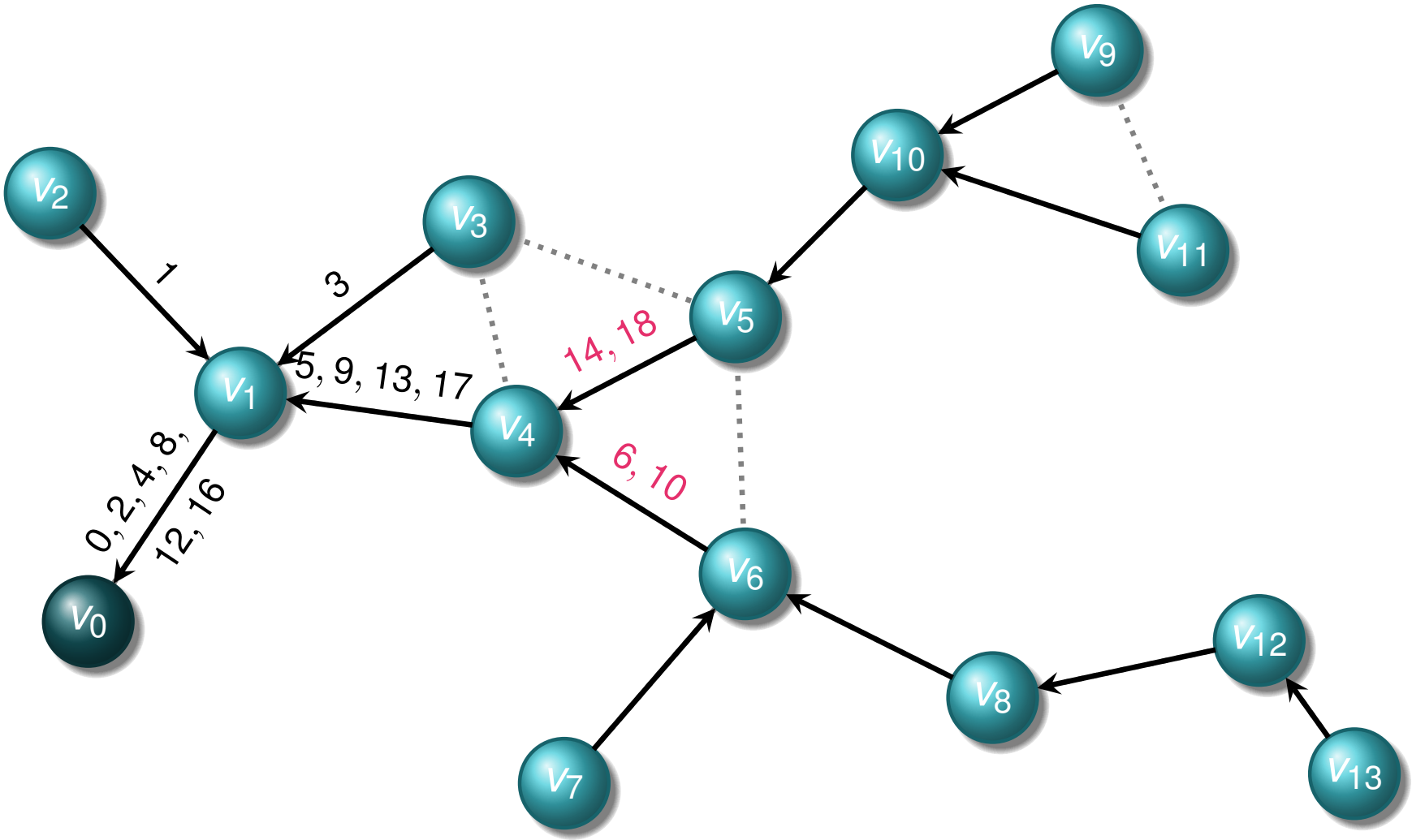

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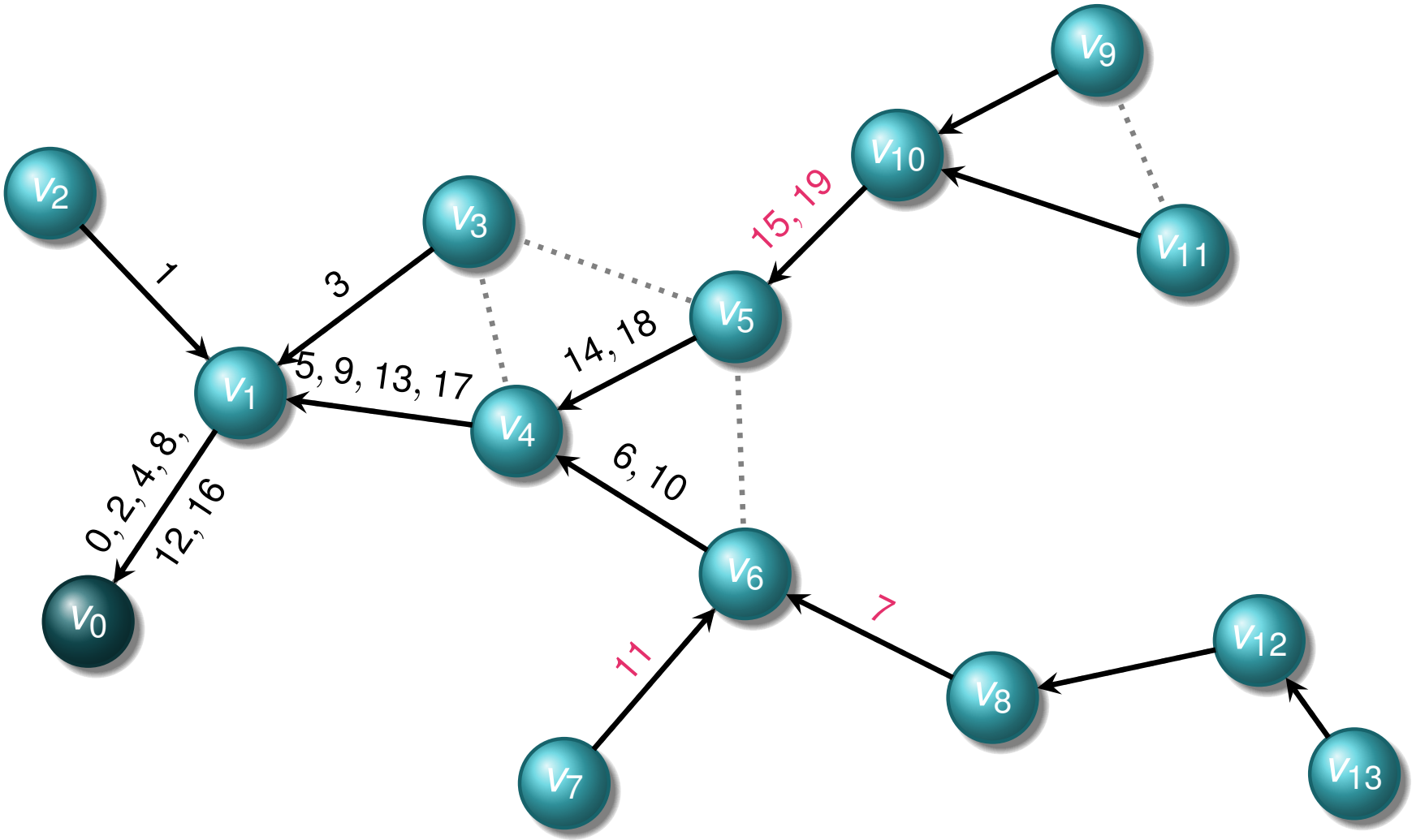

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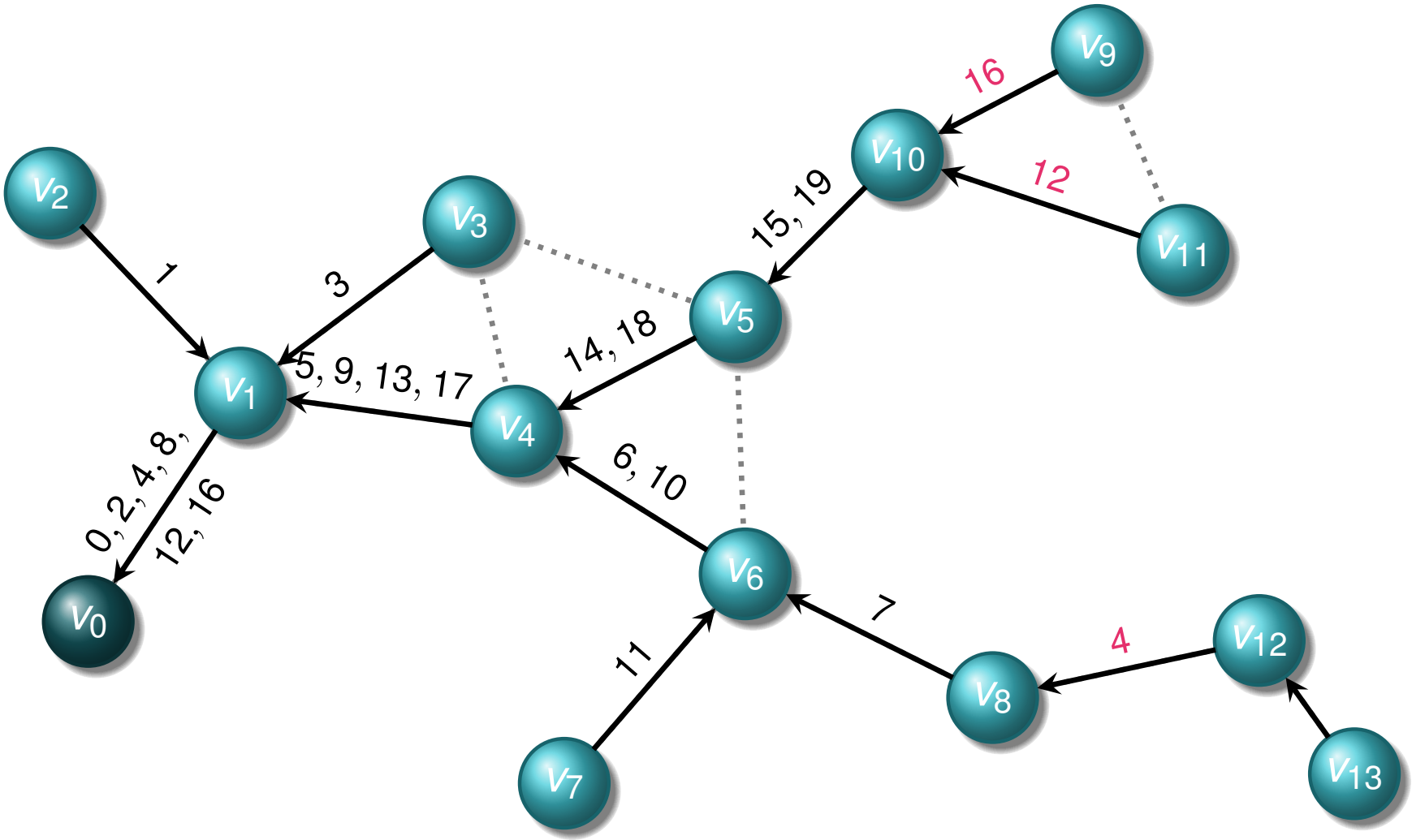

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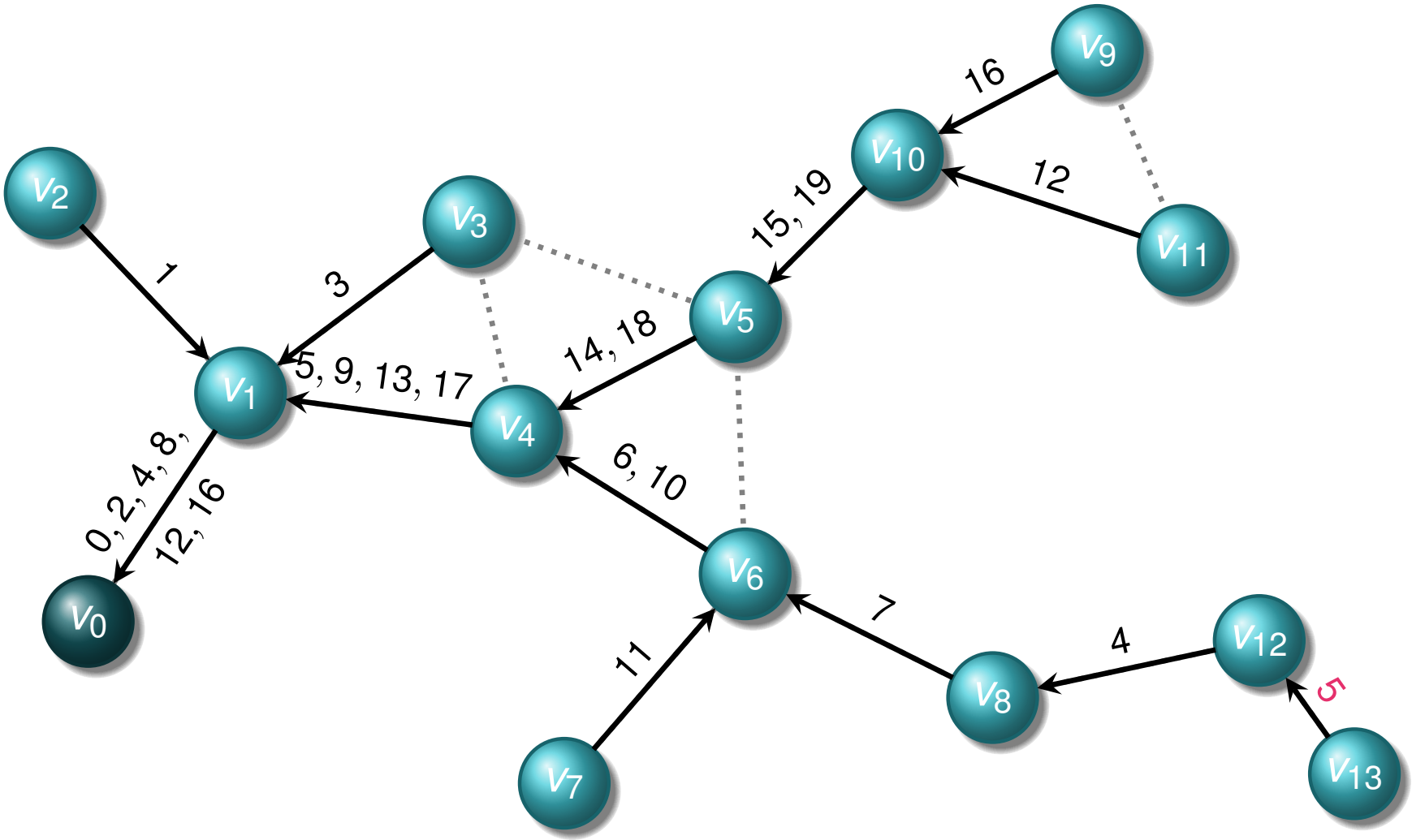

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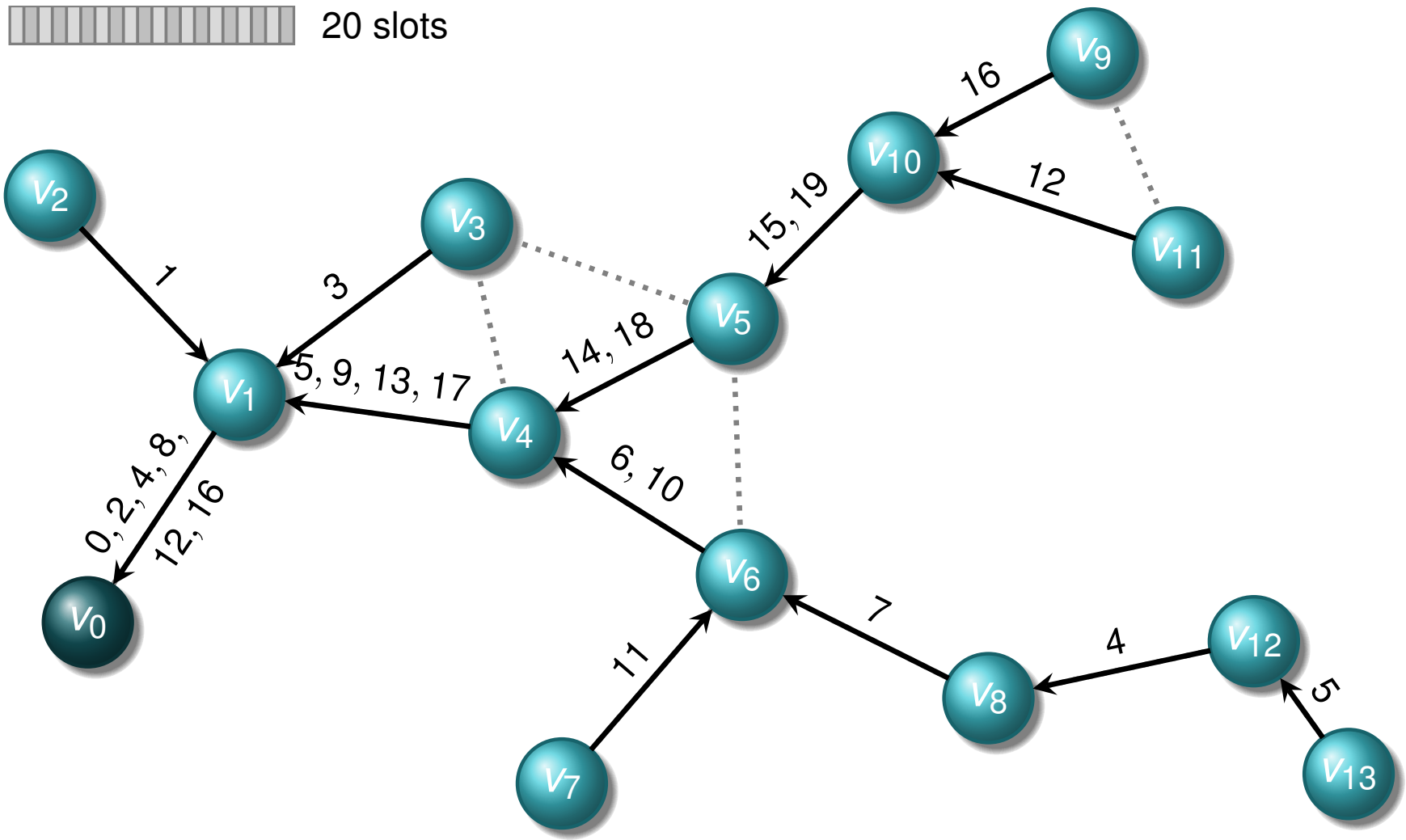
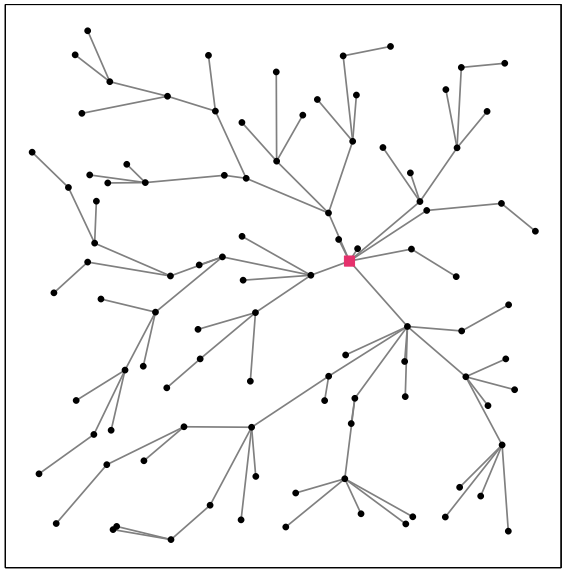
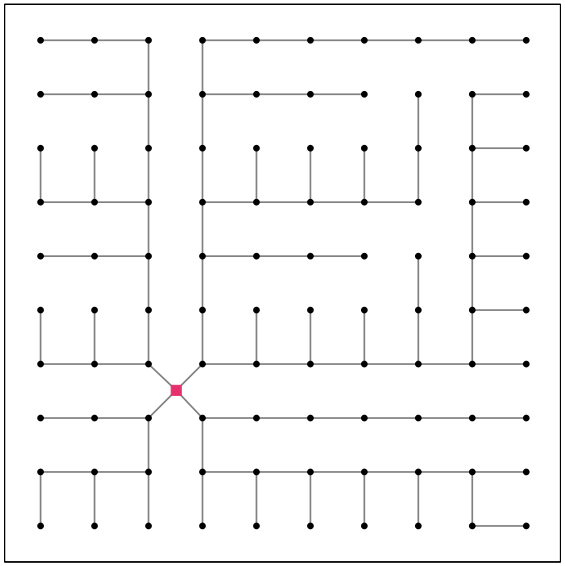
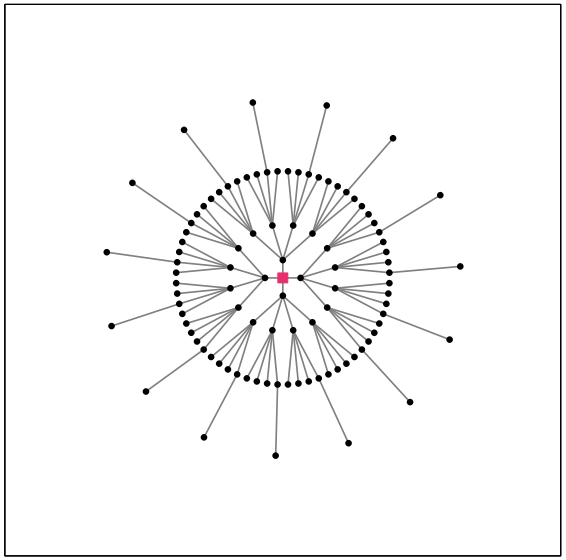


Simulation Parameters

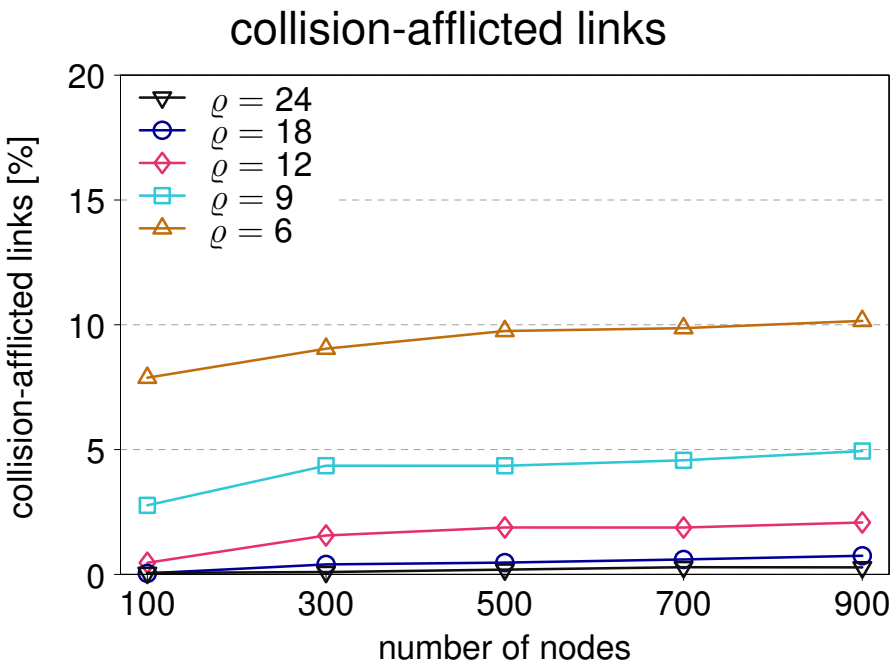


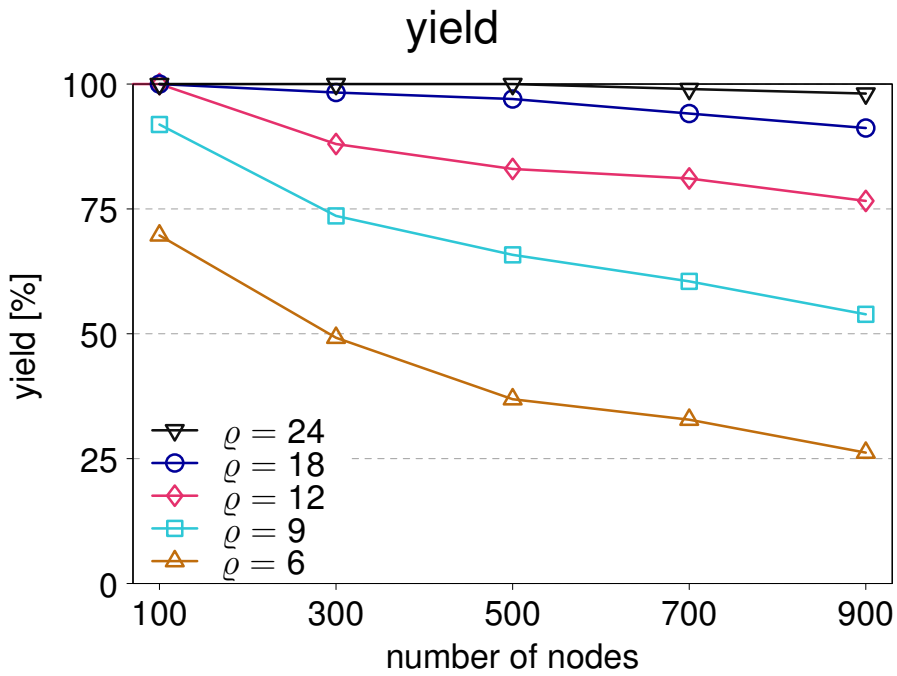




Nodes	Density	Children	Buffer	Buffer Fill Level [%]
$20-900$	$6, 9, 12, 18, 24$	$8, \infty$	$200, \infty$	$1, 10, 20, 1-20, 25-75$

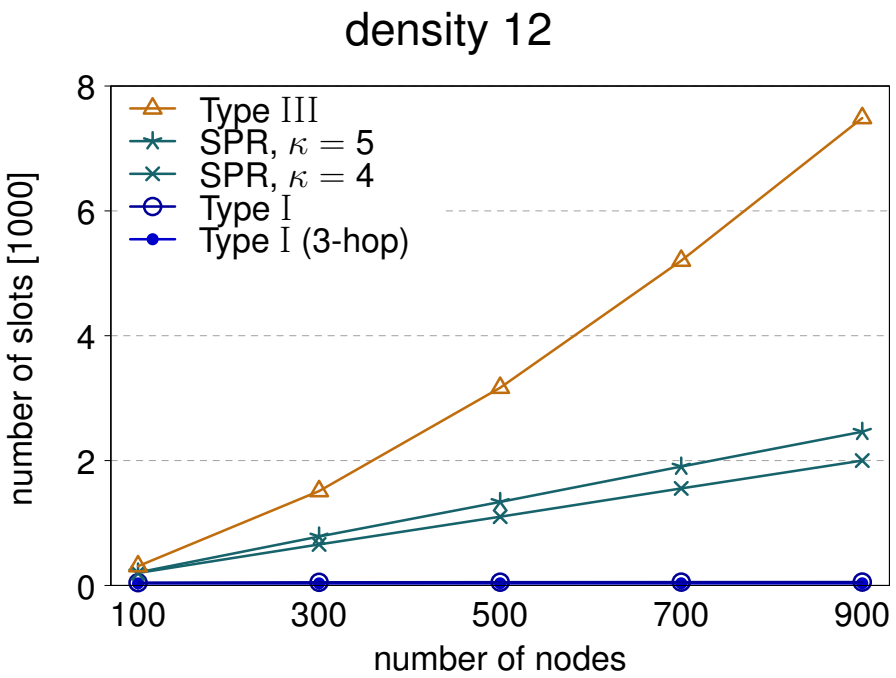
Collisions and Yield - Type I (3-hop)

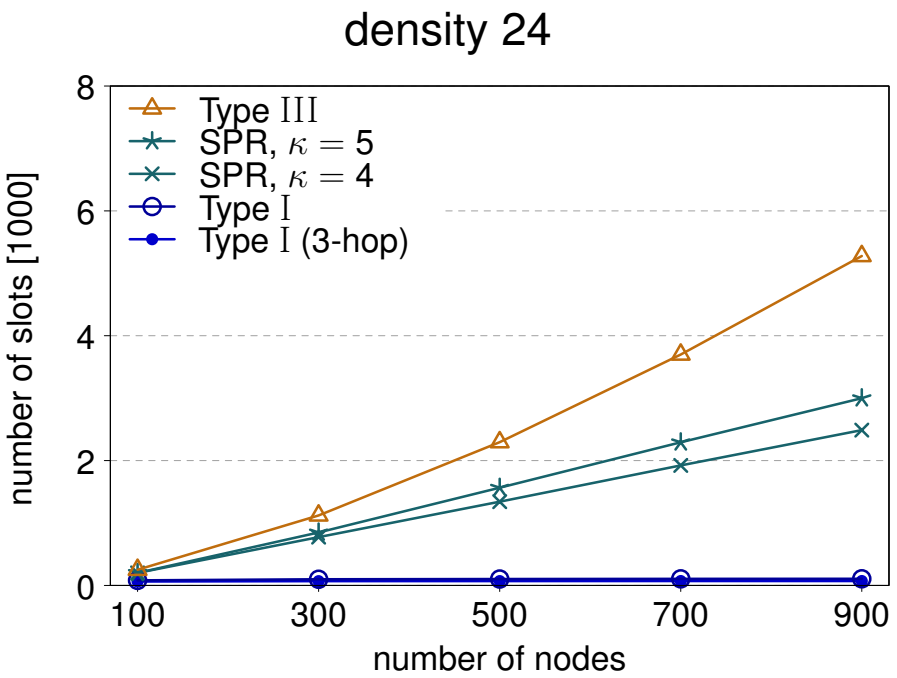




- High number of collision afflicted links
- No runtime comparability due to unacceptable yield

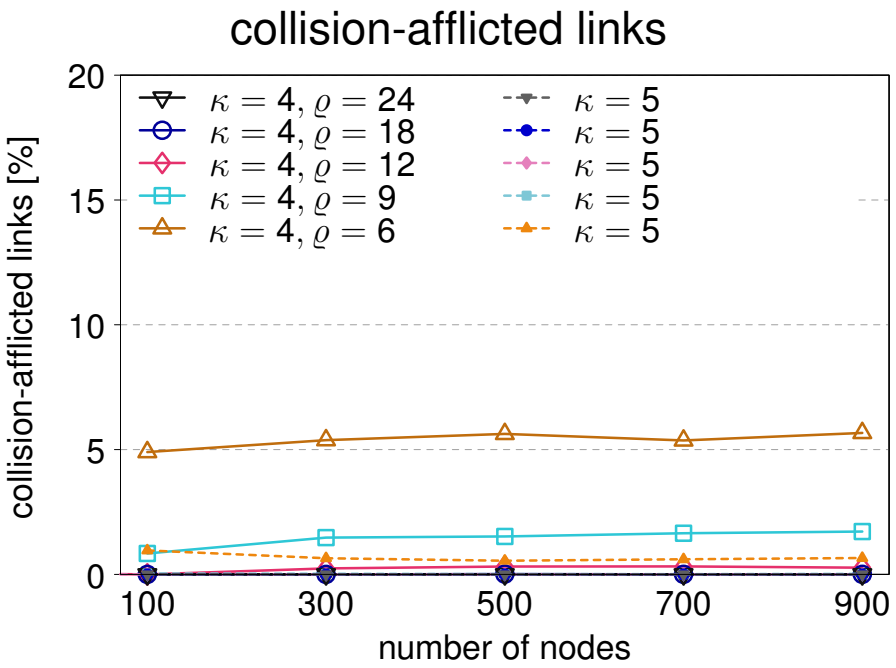
Number of Slots

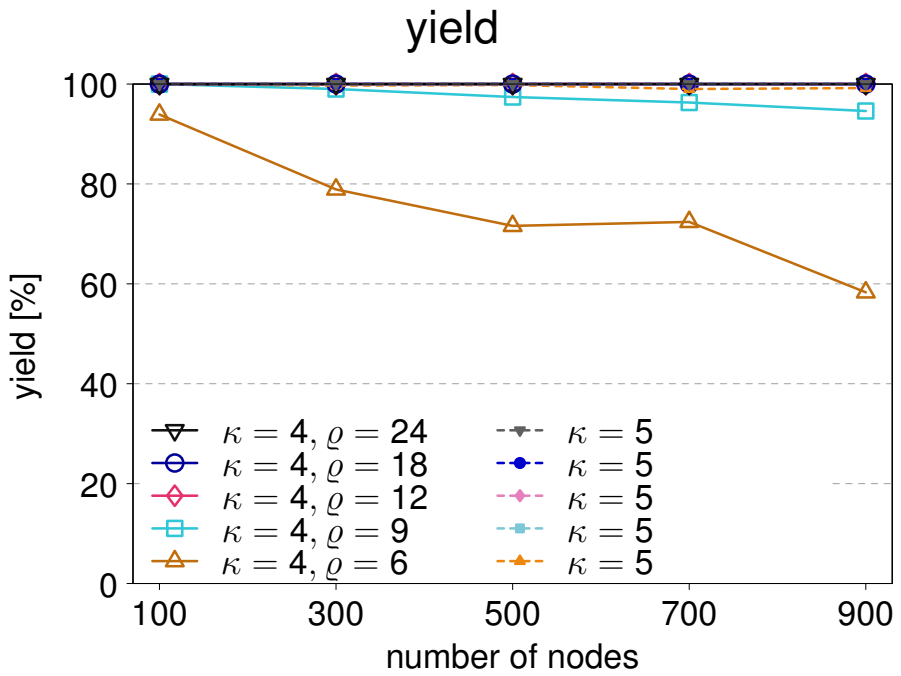




- Type I depends on density only
- Type III exposes large gradient
- SPR shows linear growth

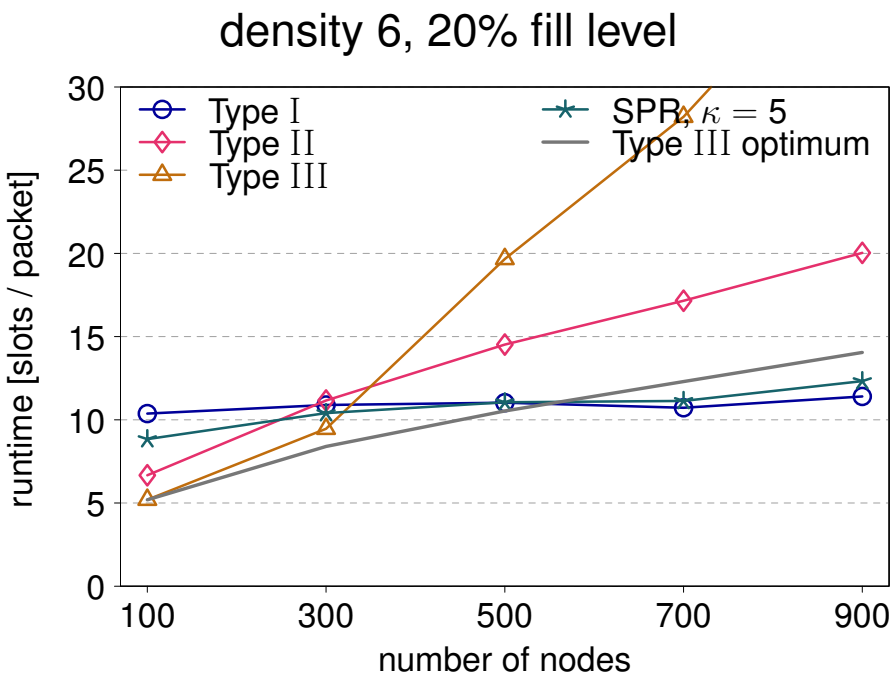
Collisions and Yield - SPR

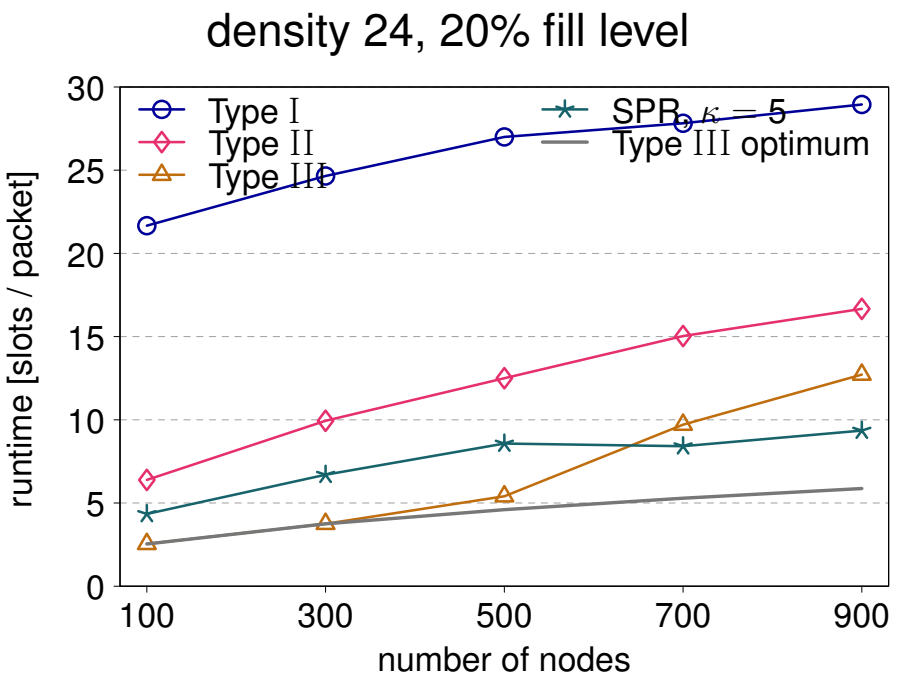




- Collisions likely for $\kappa = 4$ and in sparse networks
- Most simulations achieve 100% yield

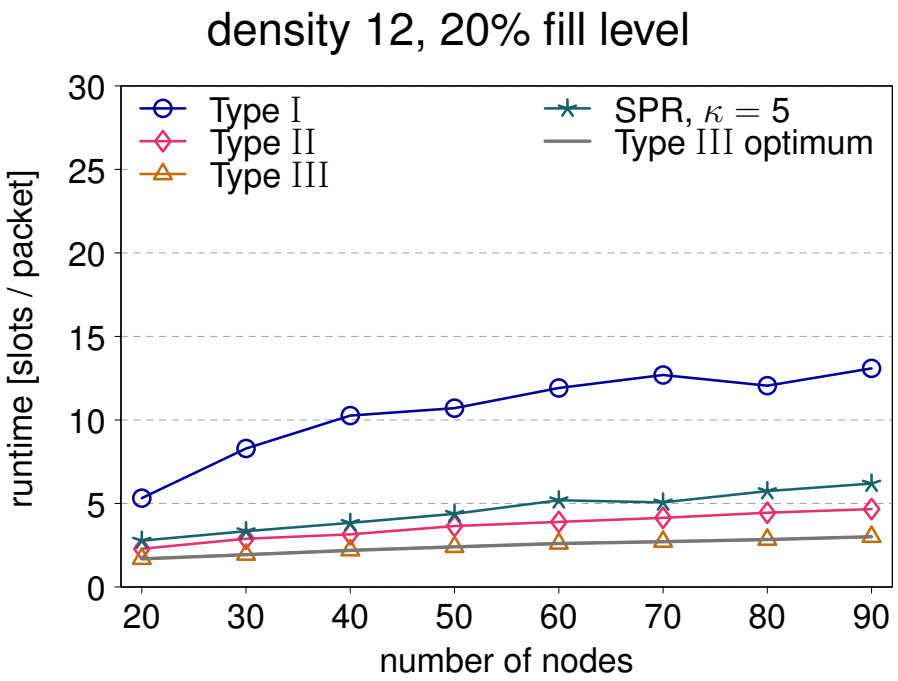
Runtime - Low and High Density

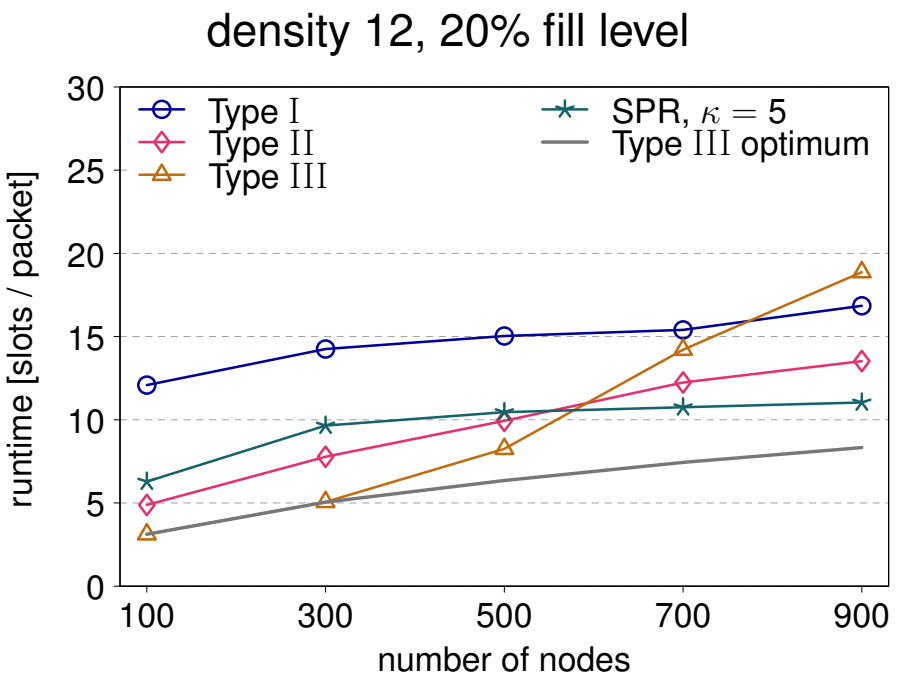




- All schedules except Type I profit from high density
- Types II and III suffer from restricted buffer size
- Optimum not reached in dense networks

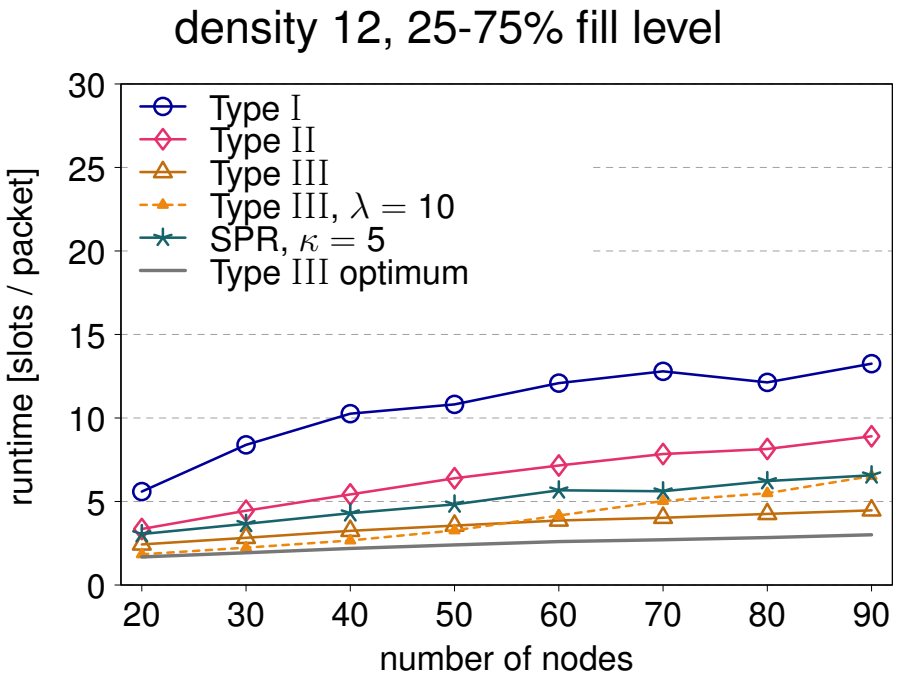
Runtime - Medium Density

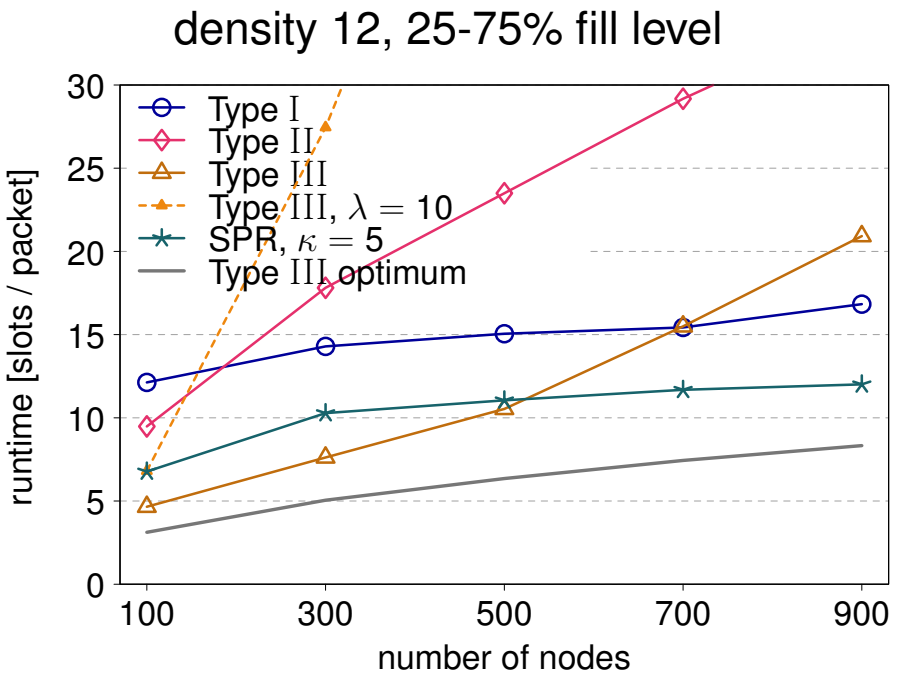




- Type I exposes poor runtime
- Type III at optimum in small and medium networks
- SPR favorable in large networks

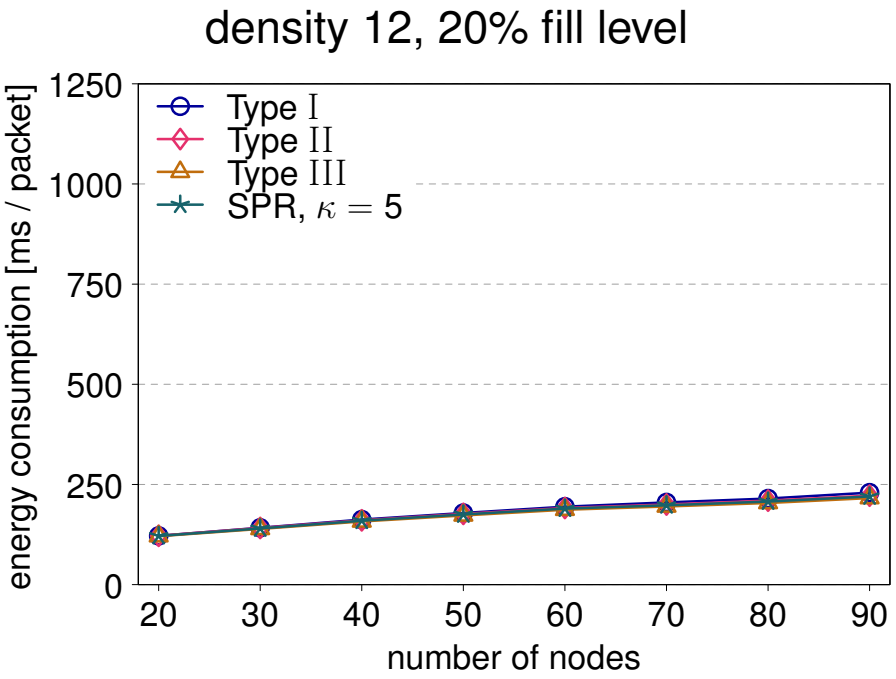
Runtime - Medium Density and High, Variable Load

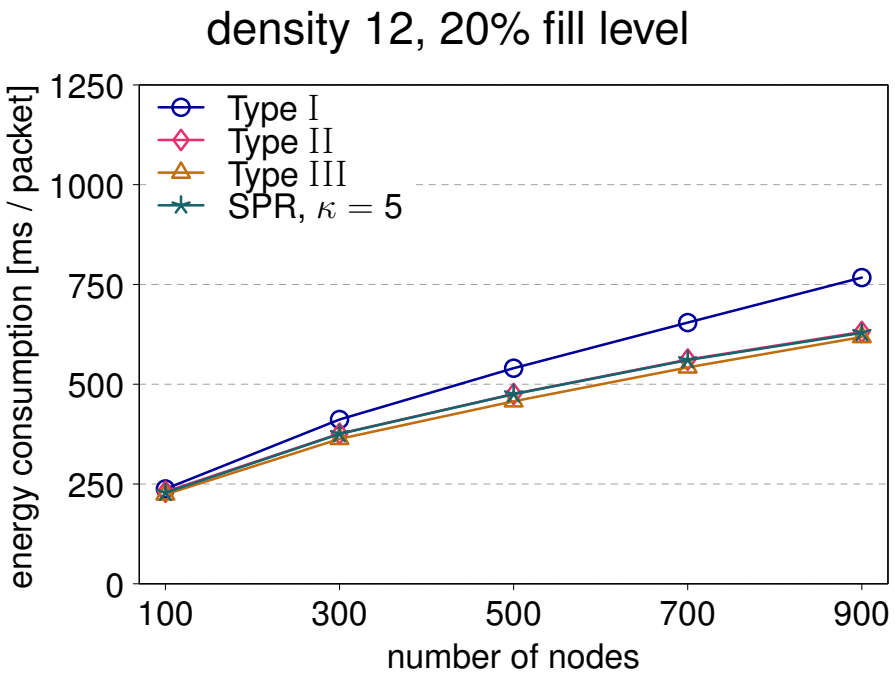




- Optimum never reached
- Type II suffers from delayed slot reuse

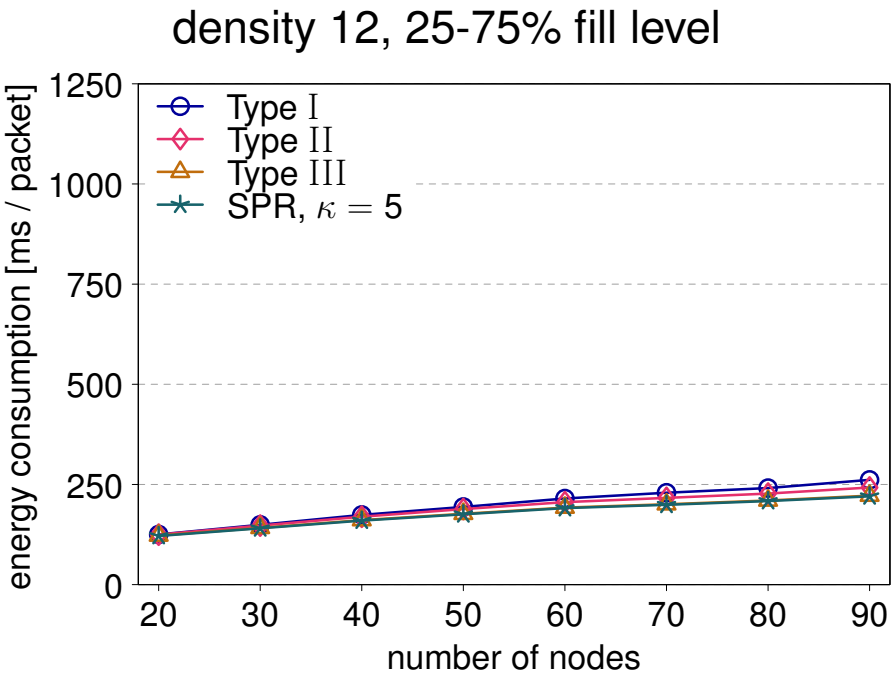
Overall Energy Consumption - Equal Load

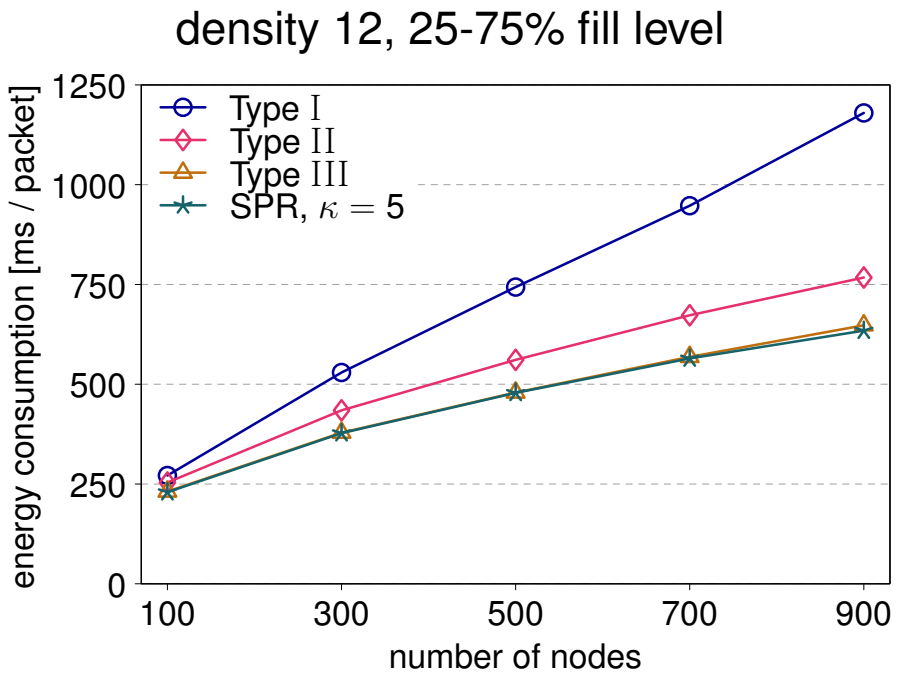




- Similar energy consumption among all schedules
- Type I: Buffer congestion provokes retransmissions

Overall Energy Consumption - High, Variable Load





- Higher load amplifies buffer congestion
- Variable load causes idle listening

Conclusion

- **Type I**
  - Collision-afflicted
  - High runtime
  - Poor energy-efficiency
- **Type II**
  - Applicable in small networks only
  - High load causes buffer congestion
- **Type III**
  - Favorable in small and medium networks
  - Restricted by buffer size
- **SPR**
  - Collision-afflicted in sparse networks
  - Best runtime in large networks
  - High energy-efficiency

Outlook

- Larger networks
- Sparse networks
- Improve flow control
- Periodical data collection
- Multiple sinks
- Networks with low or partial mobility

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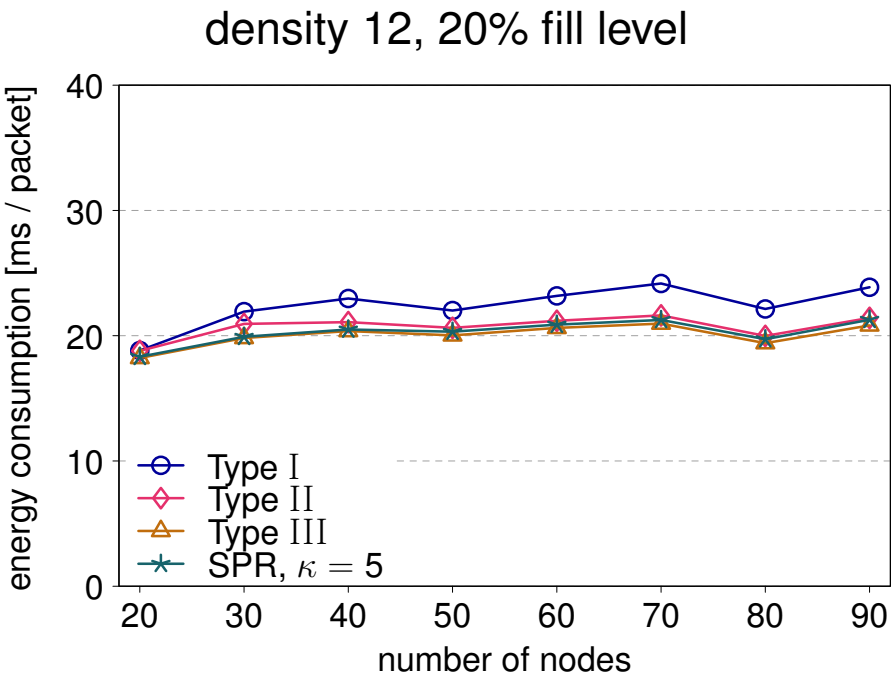
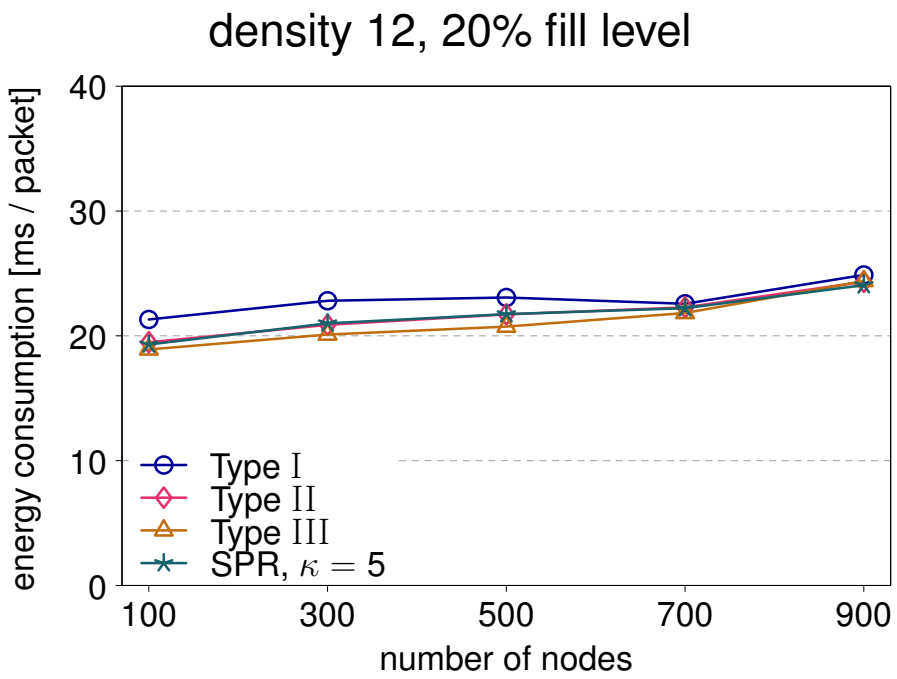
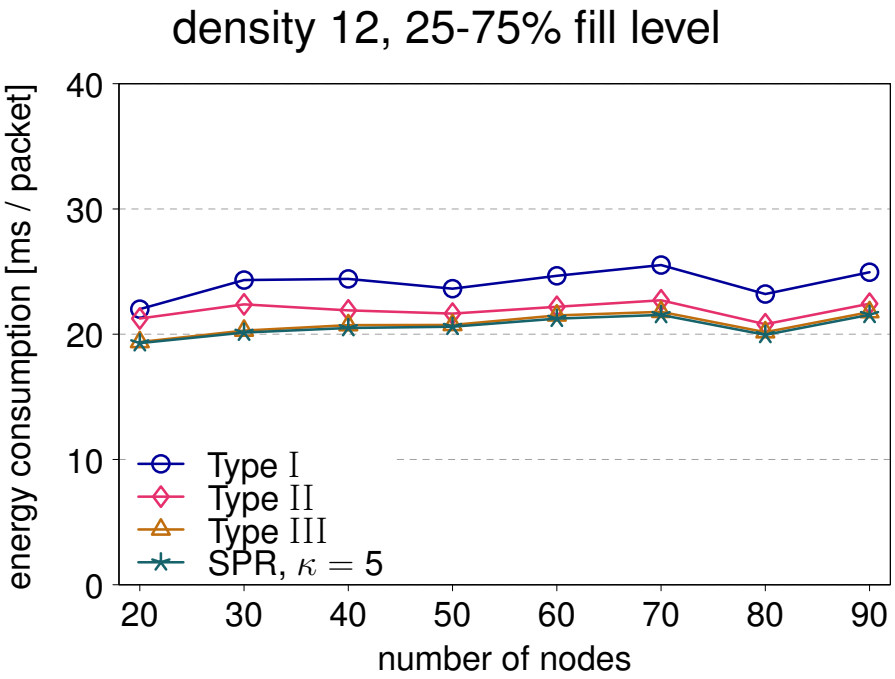
Maximum Energy Consumption - Equal Load

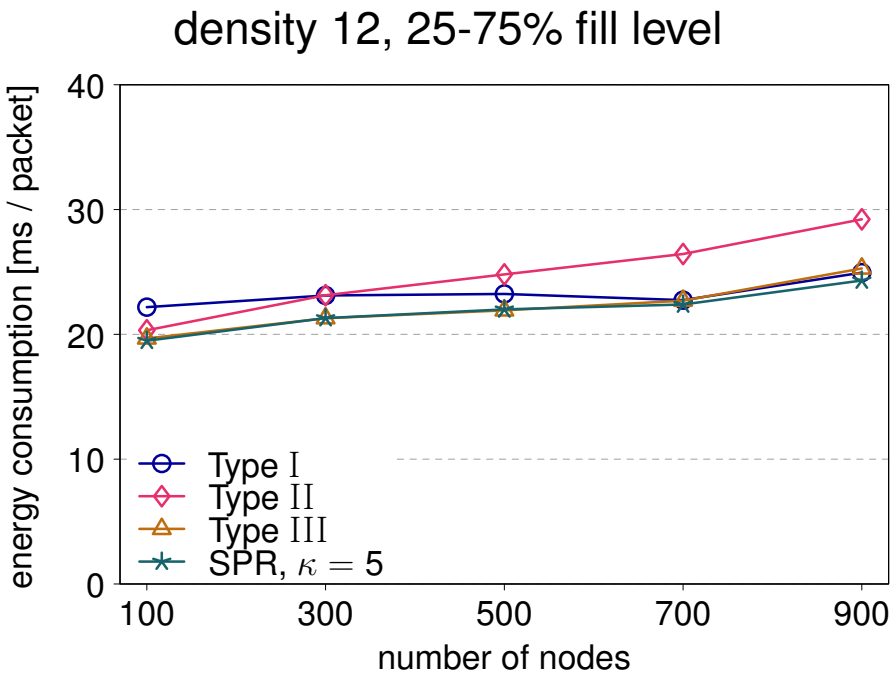




- Maximum energy per packet almost constant
- Type III: Buffer limitation provokes flow control
- SPR: Unbalanced load causes flow control

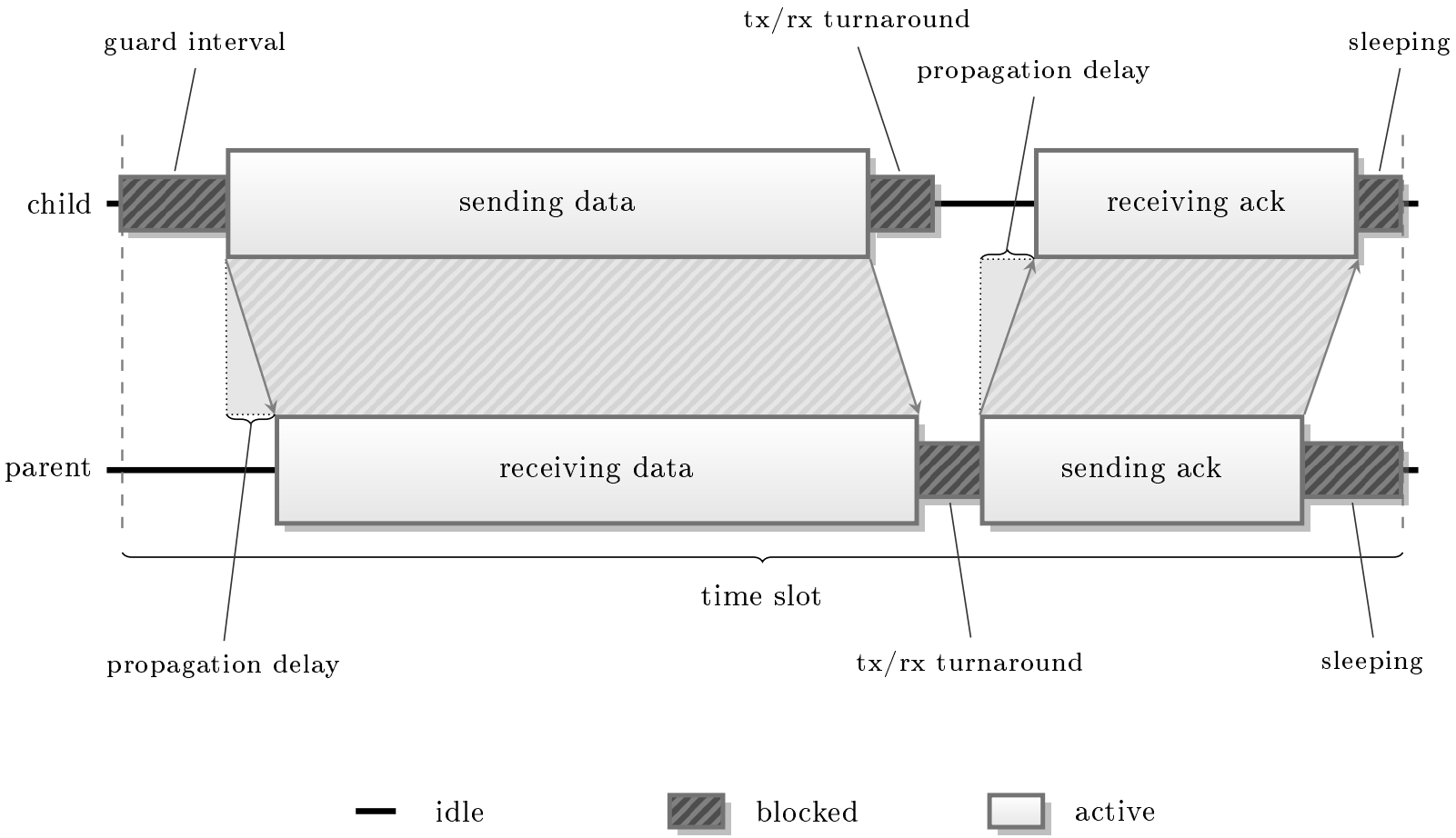
Maximum Energy Consumption - High, Variable Load





- Energy per packet barely influenced by load
- Reuse strategy of Type II insufficient under high load

TDMA Slot Layout



Analytical Comparison

	Type I k-hop	Type II enhanced	Type III plain	SPR
Lower Bound for R	ϱ	$N-1$	$N\left(h^{\star}-\frac{C}{C-1}\right)$	κ
Upper Bound for R	$N-1$	$N-1$	$\frac{1}{2}\left(N^2-N\right)$	$\frac{C}{C+1}\kappa N$
Slot Storage	$\mathcal{O}(C)$	$\mathcal{O}(CN)$	$\mathcal{O}(C)$	$\mathcal{O}(C\kappa)$
Lower Bound for T	$\frac{\varrho}{C}(N-1)L$	$NL\left(h^{\star}-\frac{C}{C-1}\right)$	$NL\left(h^{\star}-\frac{C}{C-1}\right)$	$NL\left(\min(h^{\star},\kappa)-\frac{C}{C-1}\right)$
Buffer Overflow	✓	✓	✓	–
Buffer Underrun	–	✓	✓	✓