ROMA TRE
UNIVERSITÀ DEGLI STUDI

University of Leicester

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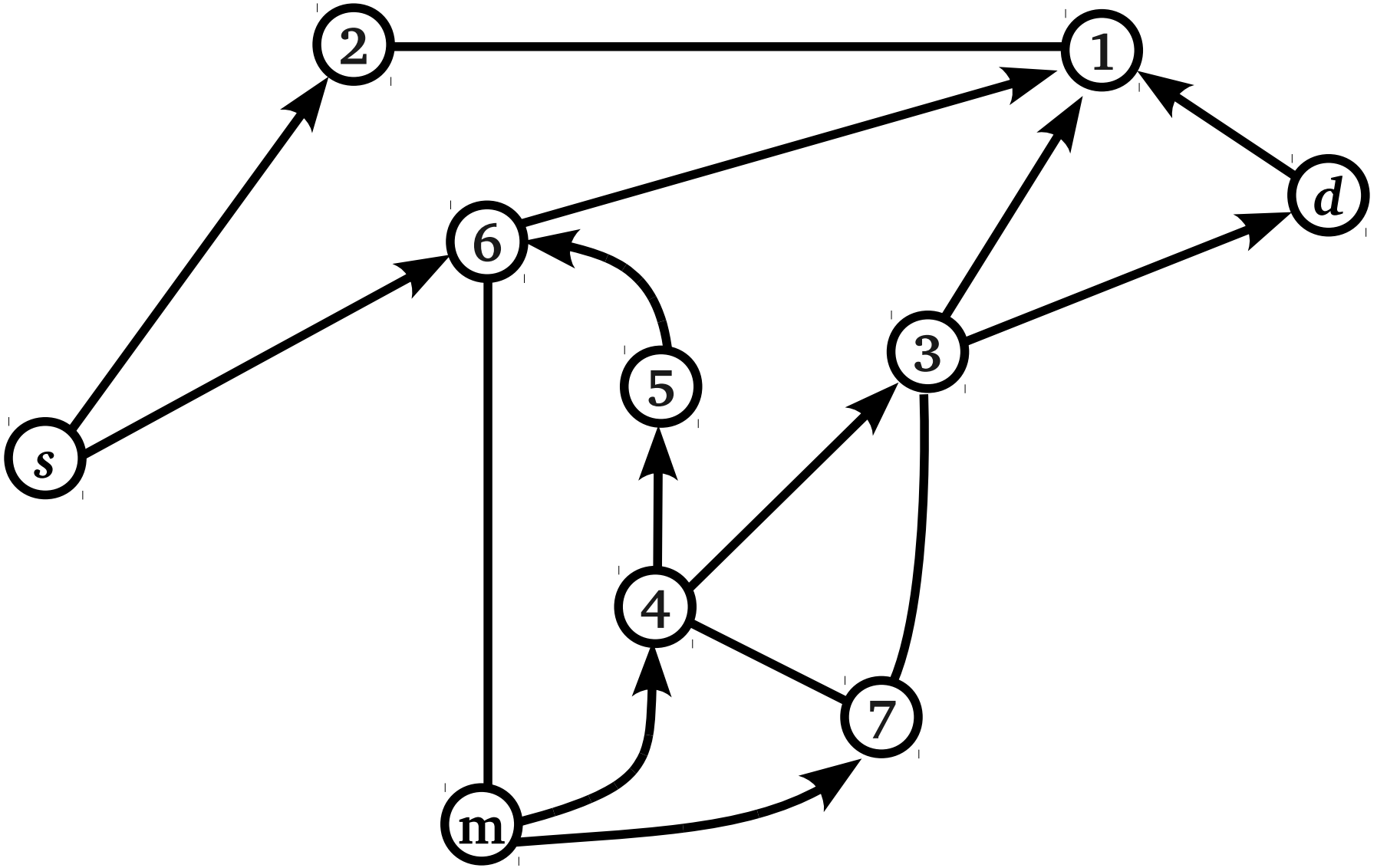
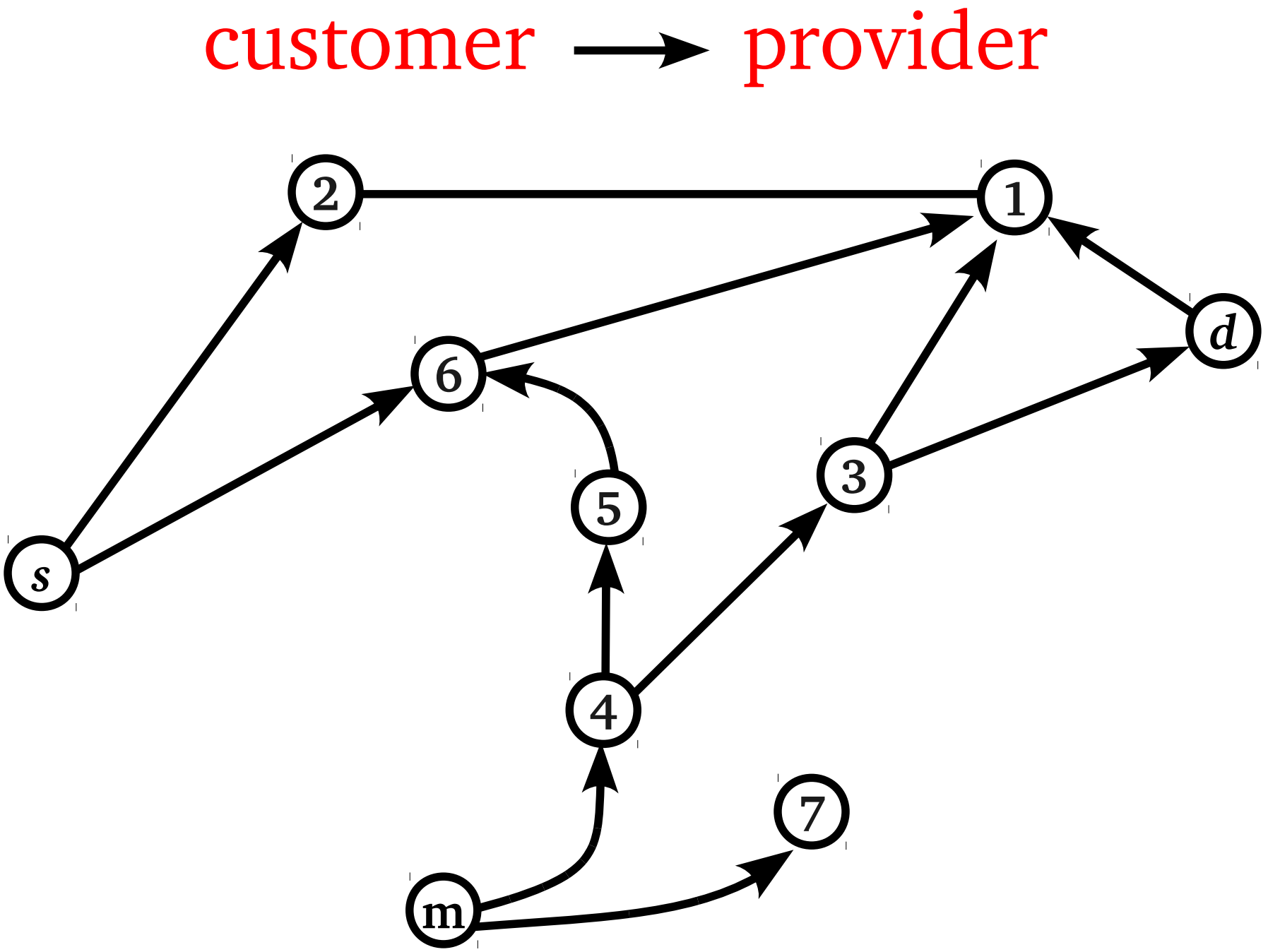
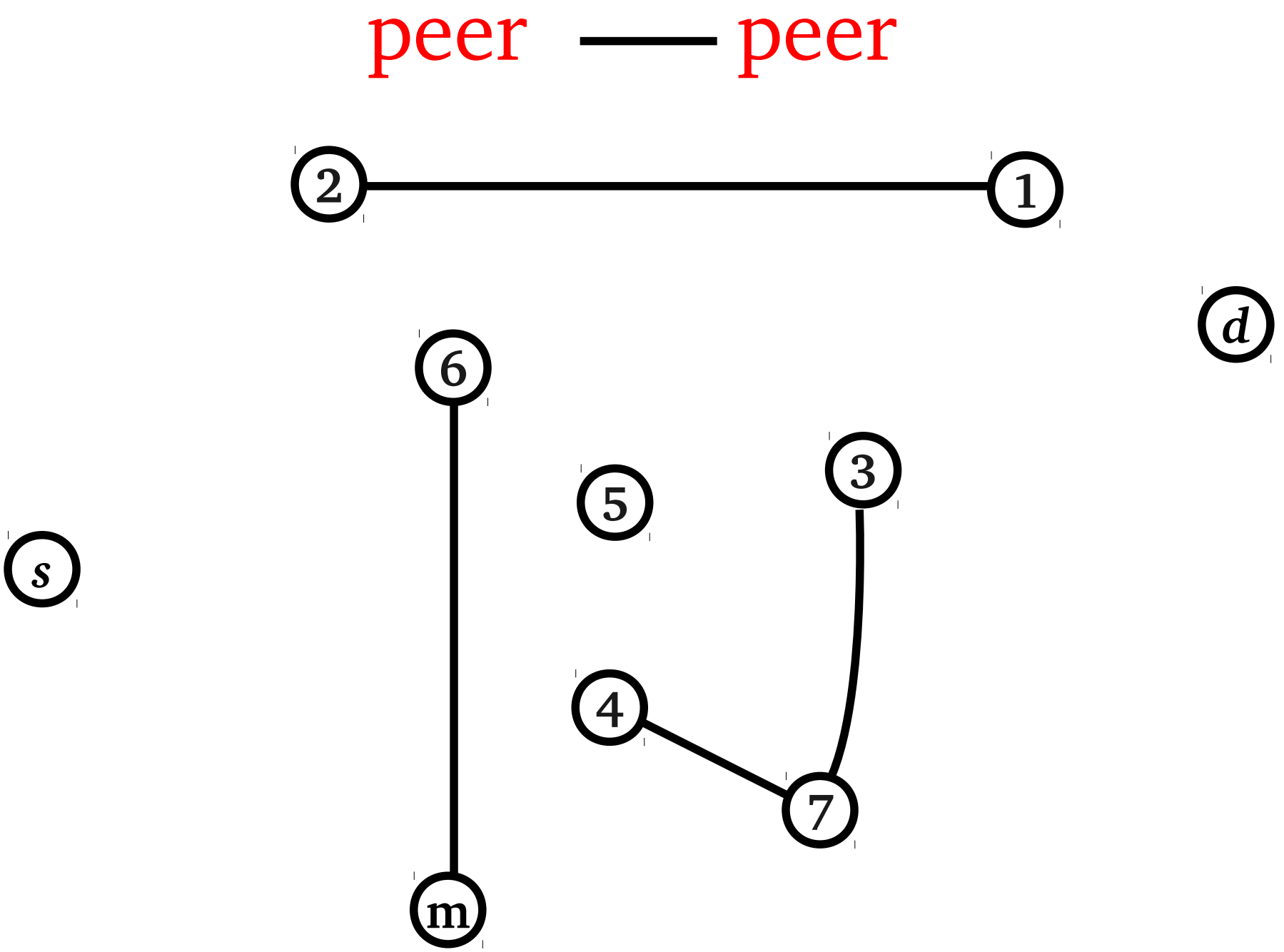
Computational Complexity of Traffic Hijacking under BGP and S-BGP

Marco Chiesa (Roma Tre University)
Giuseppe Di Battista (Roma Tre University)
Thomas Erlebach (University of Leicester)
Maurizio Patrignani (Roma Tre University)

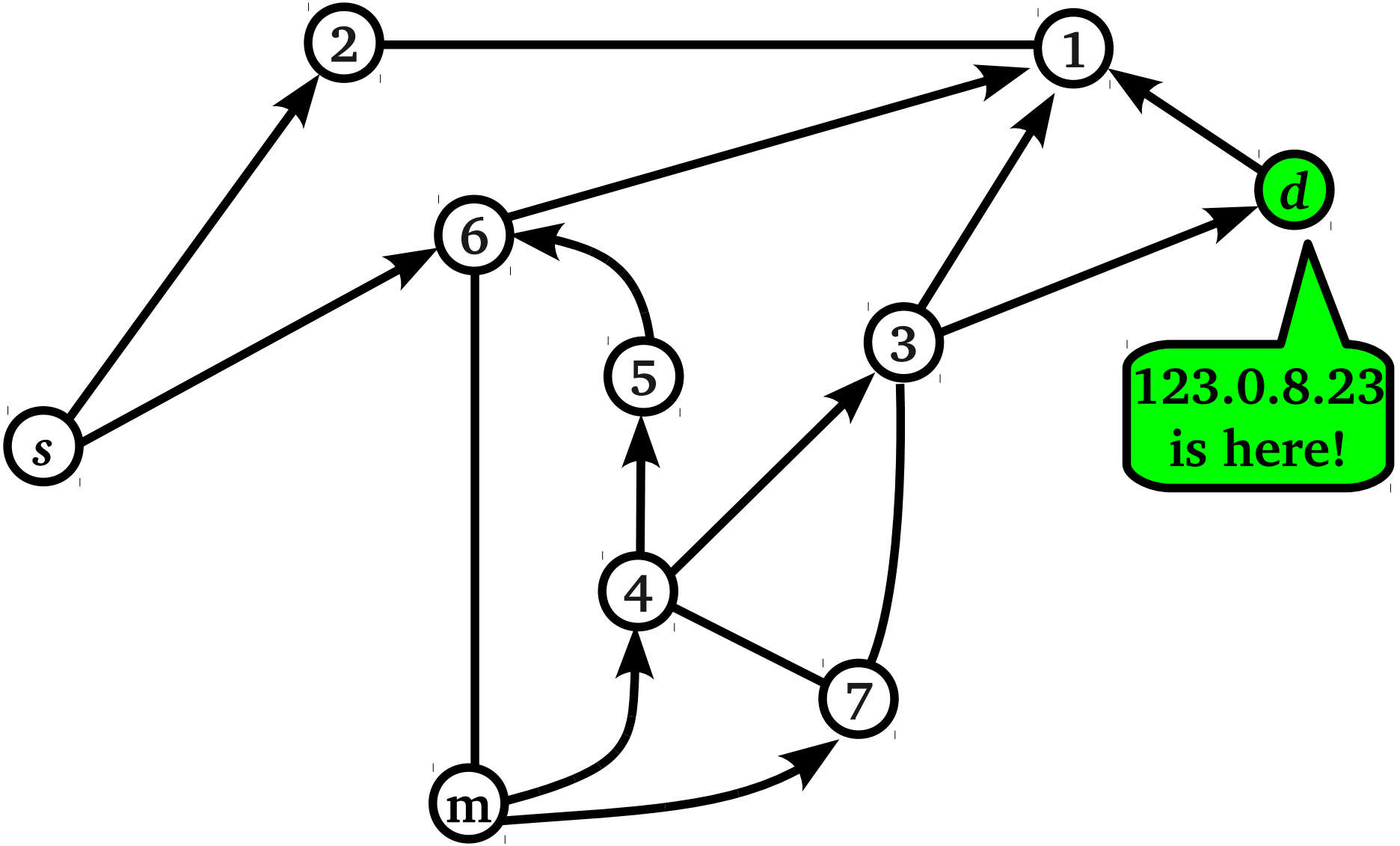
the BGP graph



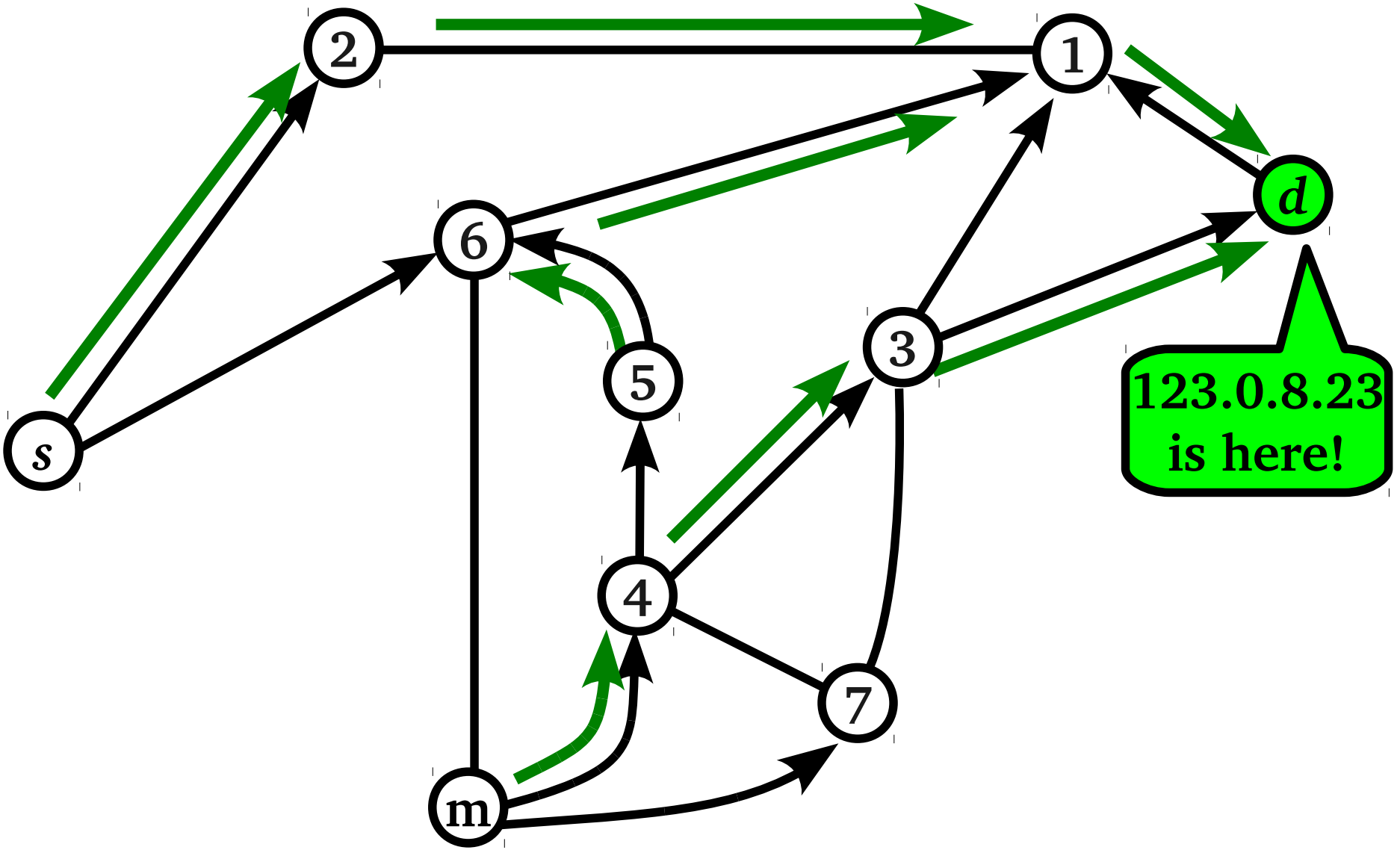

customer → provider
2
1
d
6
3
5
s
4
7
m


peer
peer
2
1
d
6
3
5
s
4
7
m

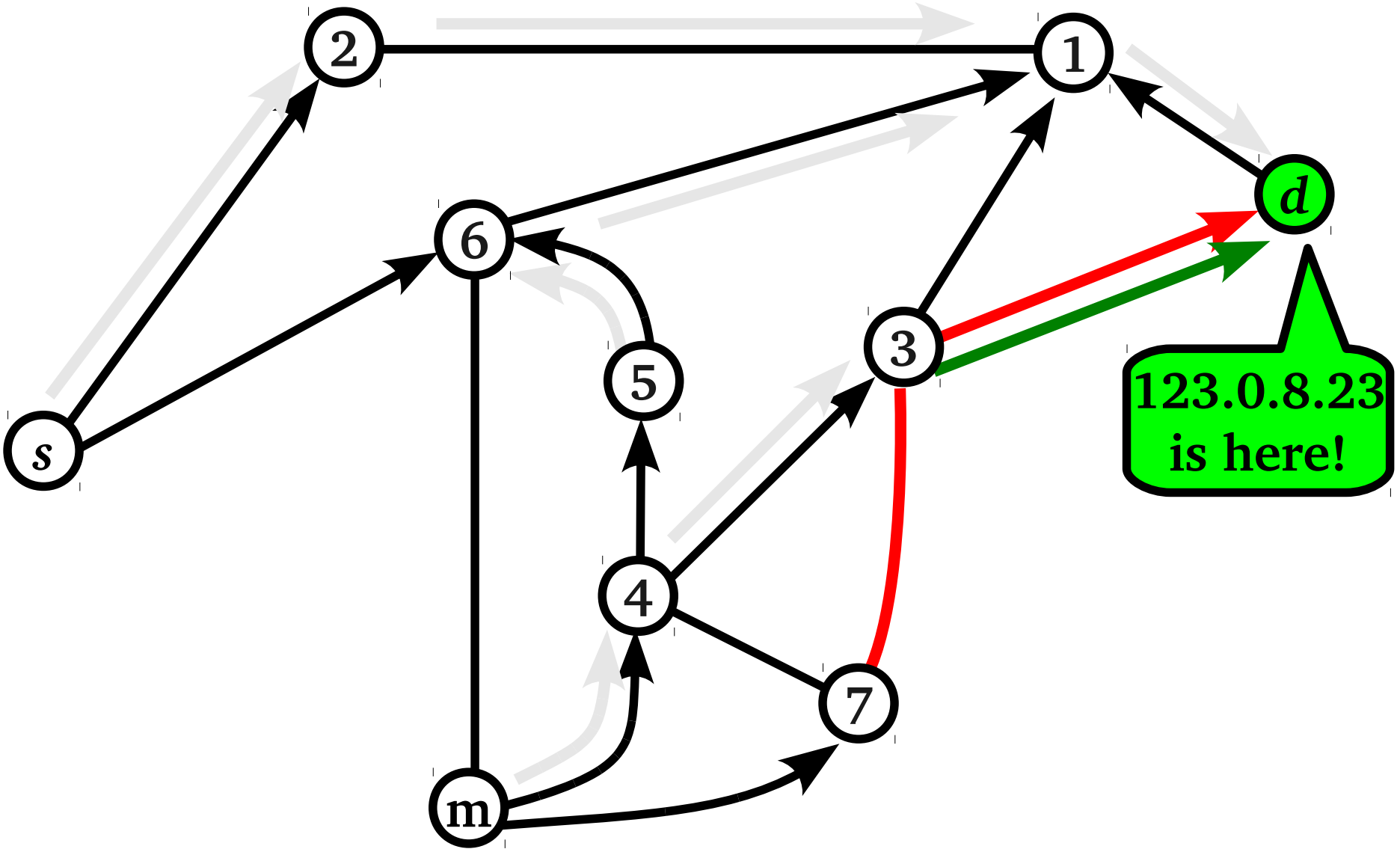
destination vertex



BGP routing tree



only valley-free paths are valid



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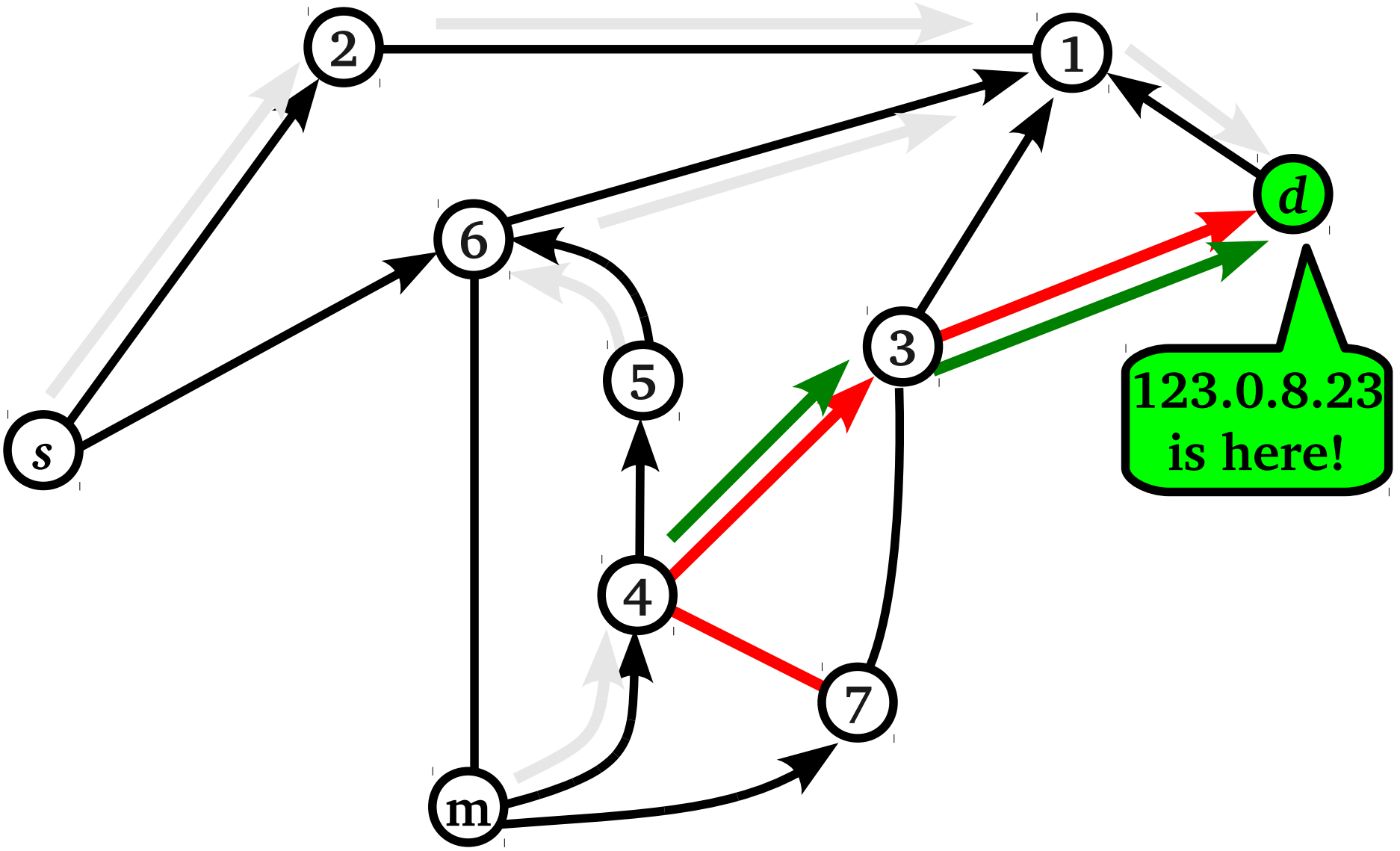

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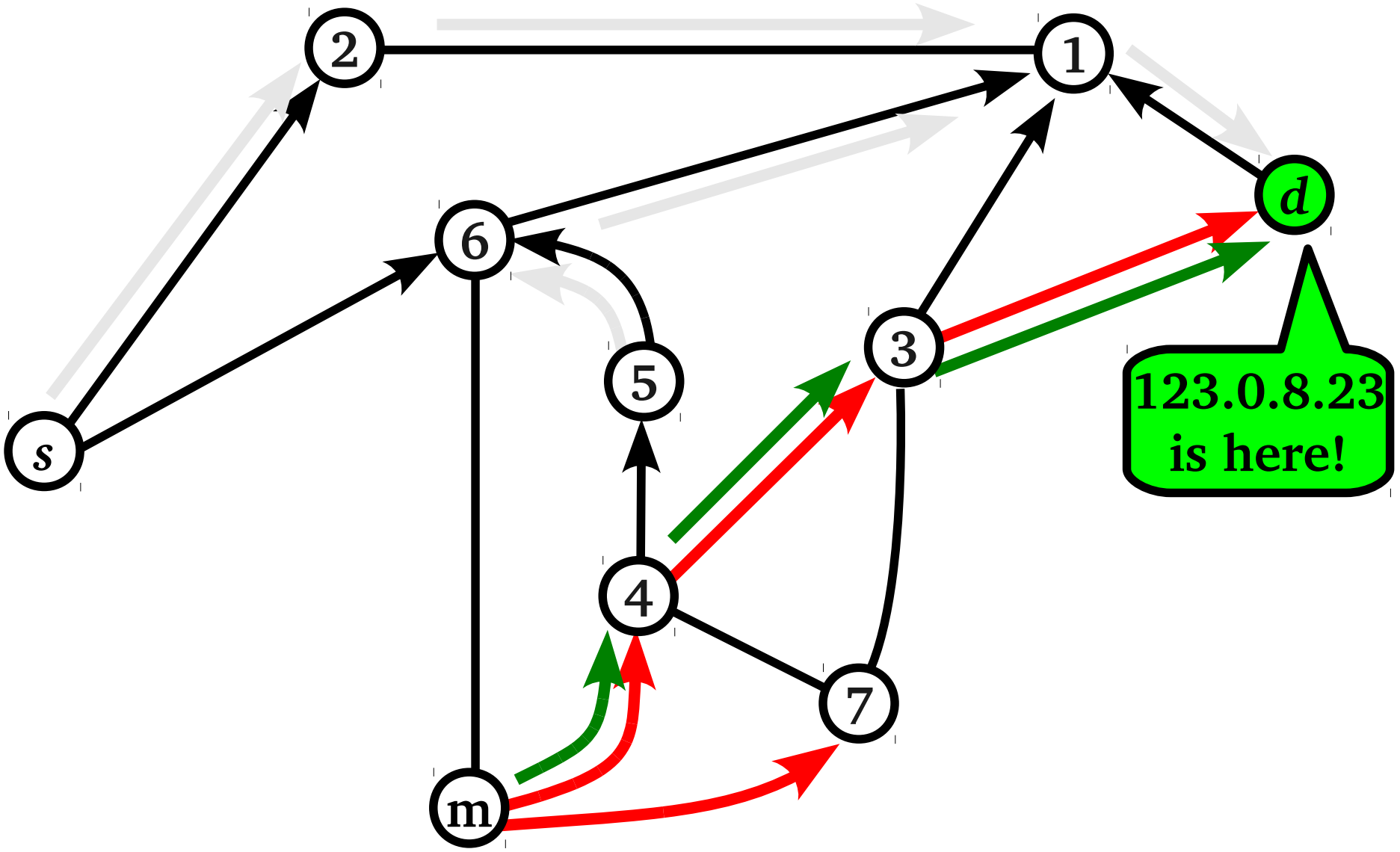
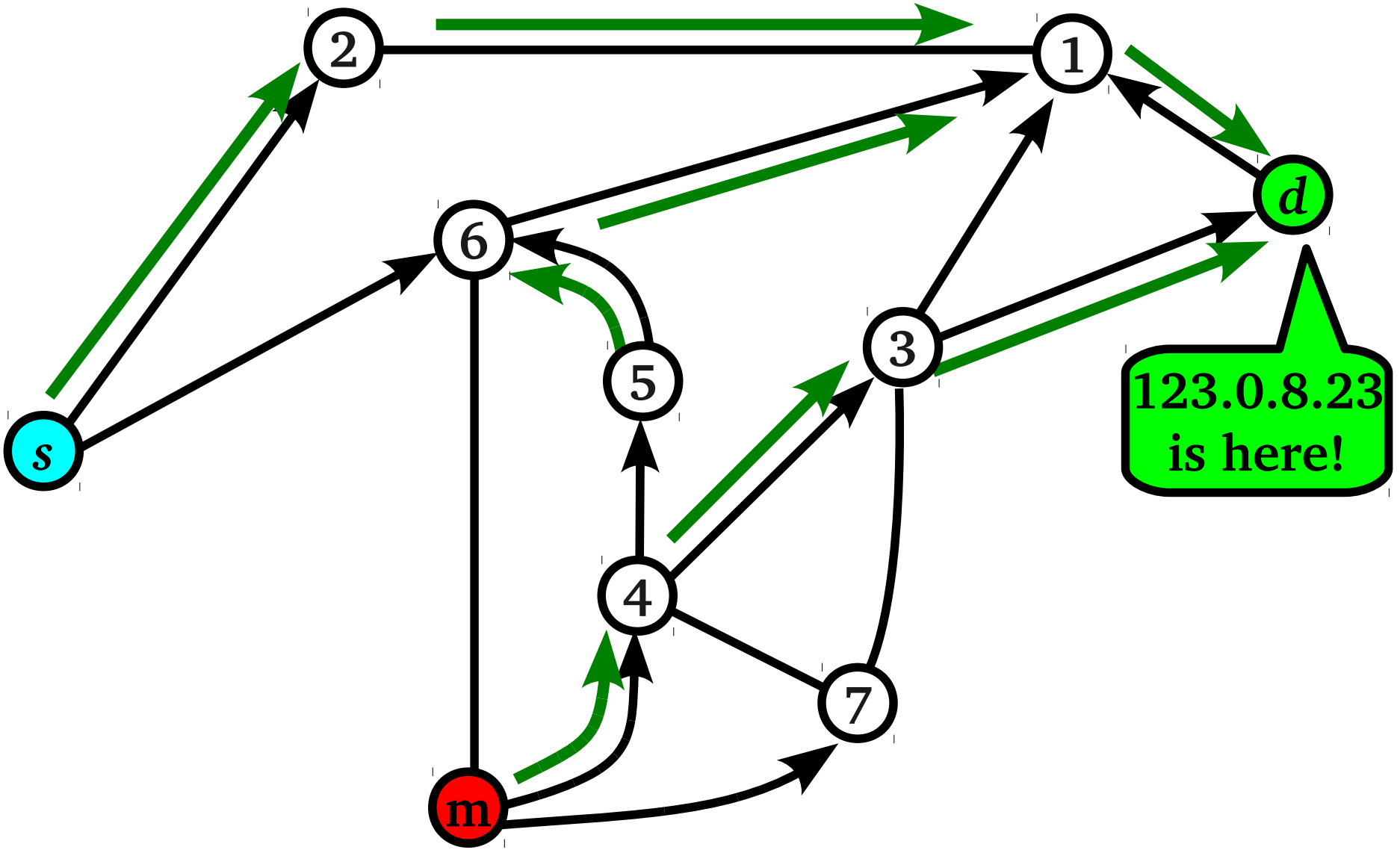
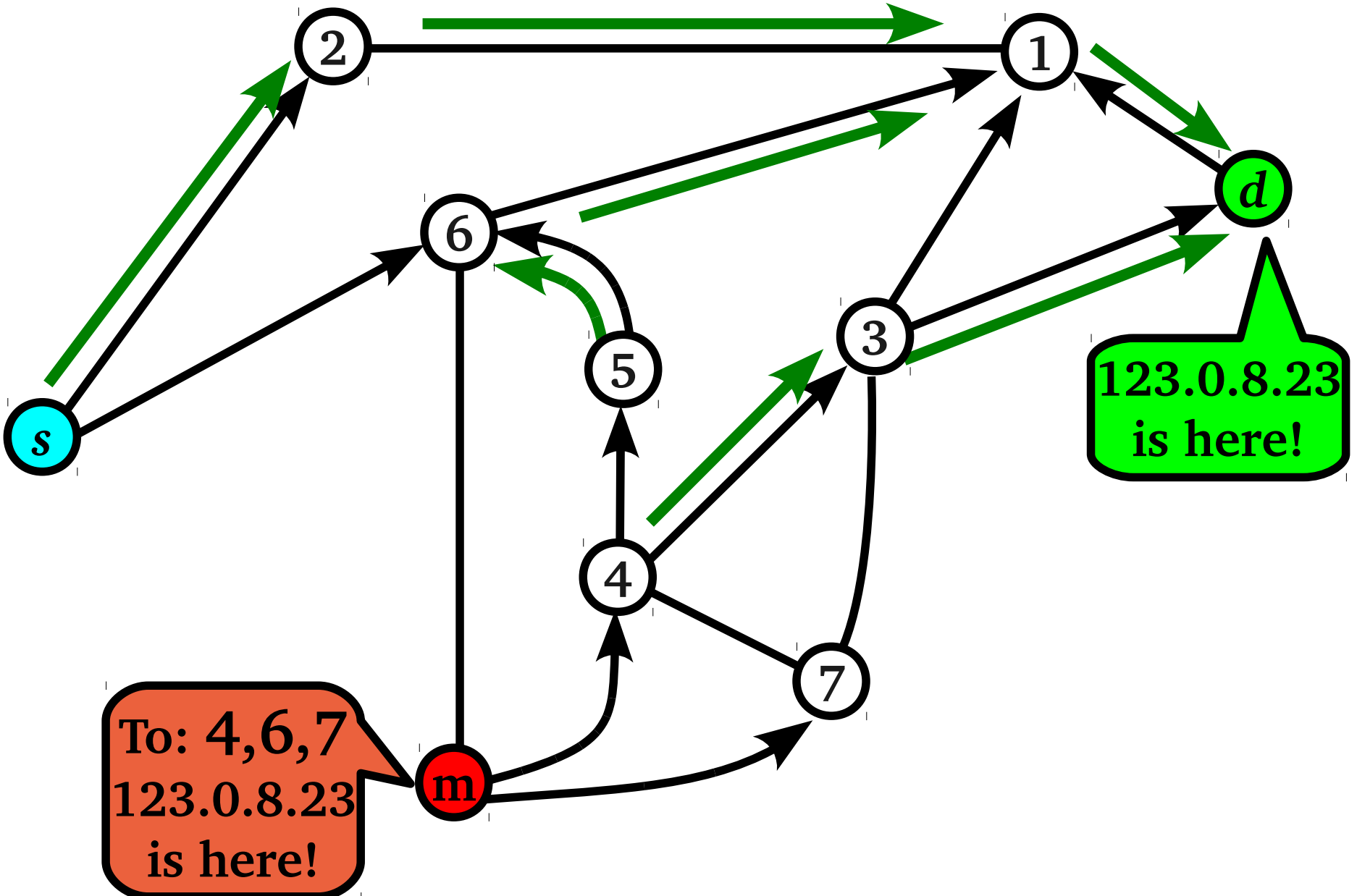


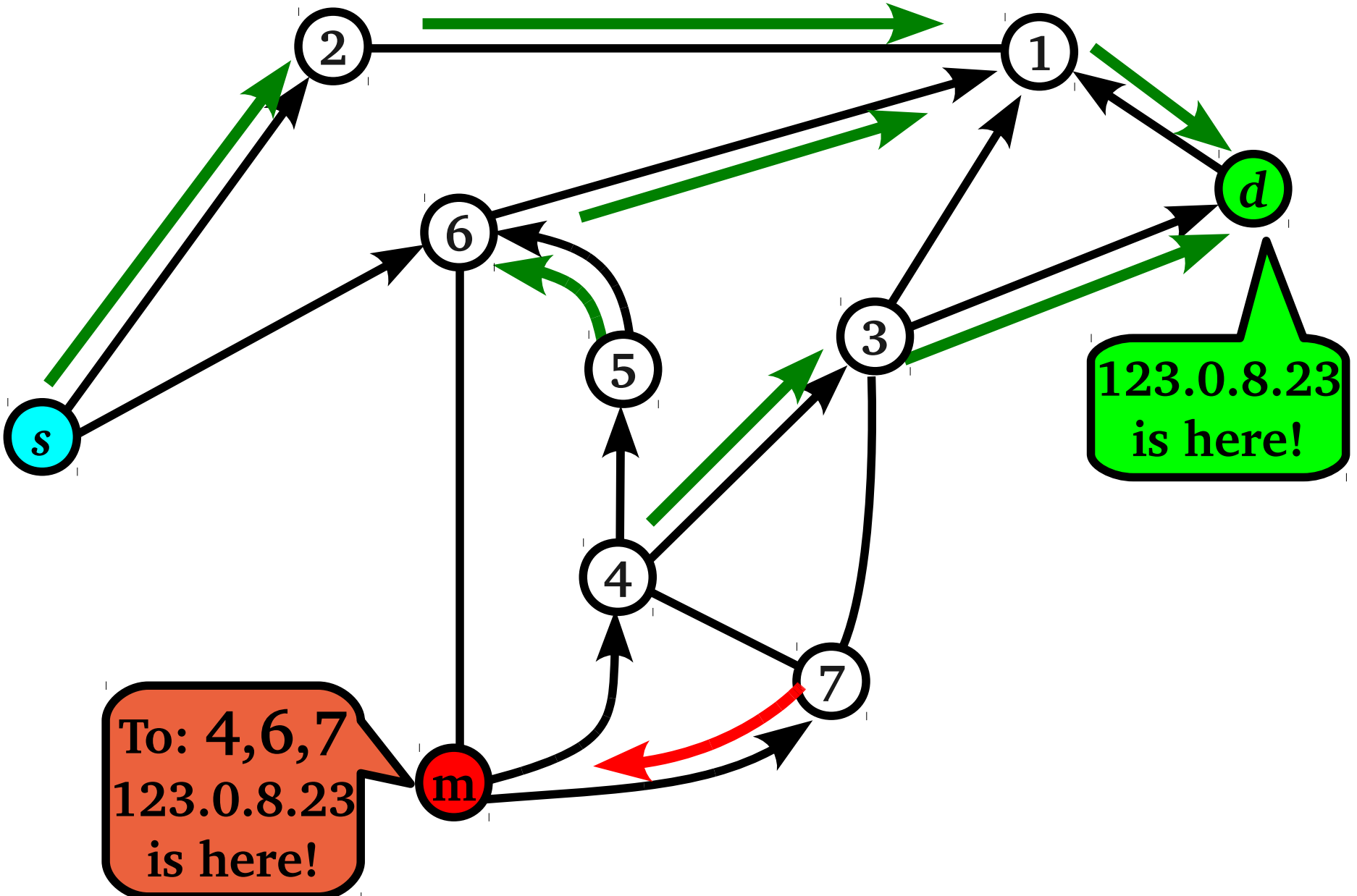
source and manipulator



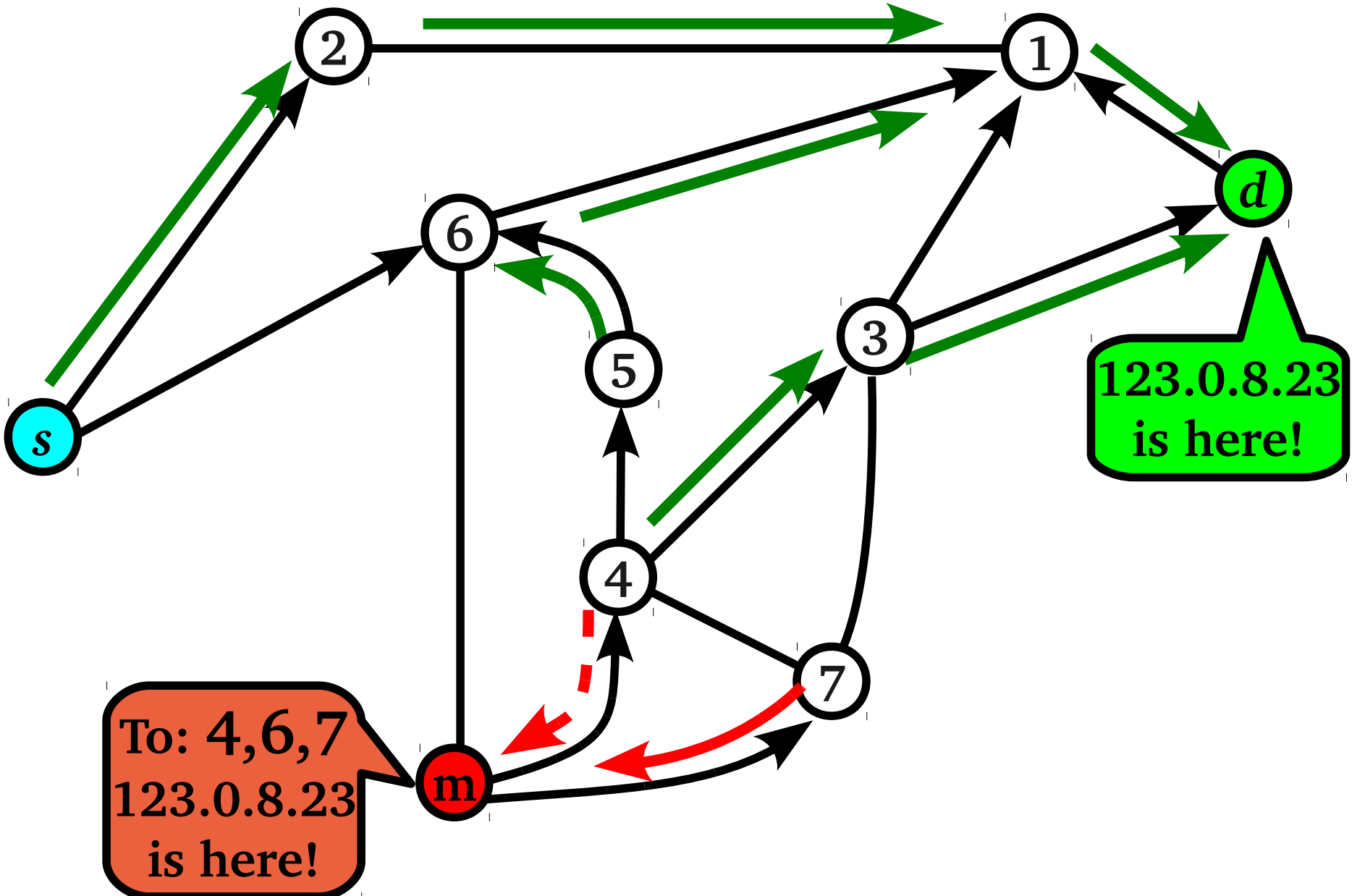
manipulator goal: hijack source



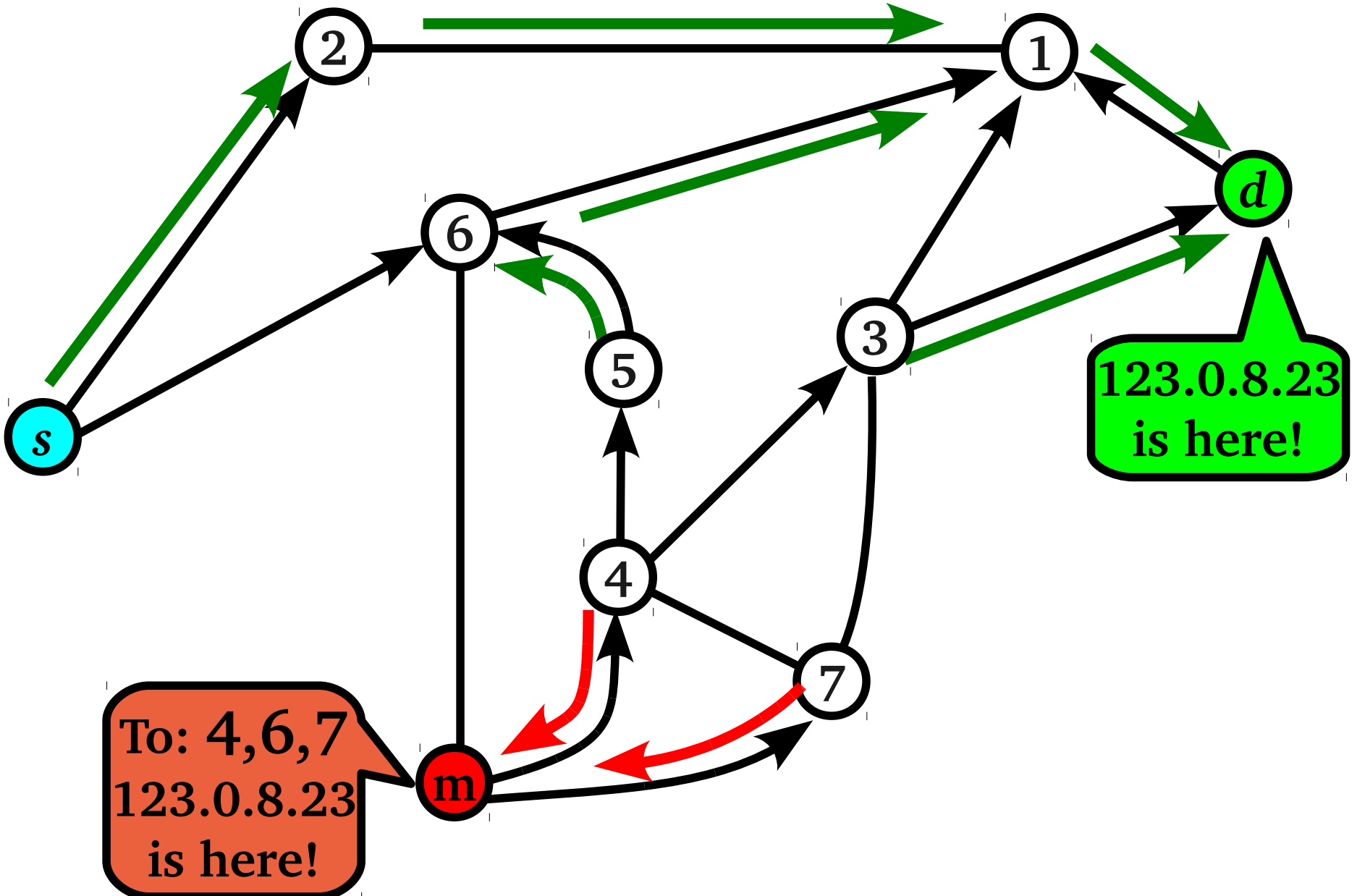
example of hijacking



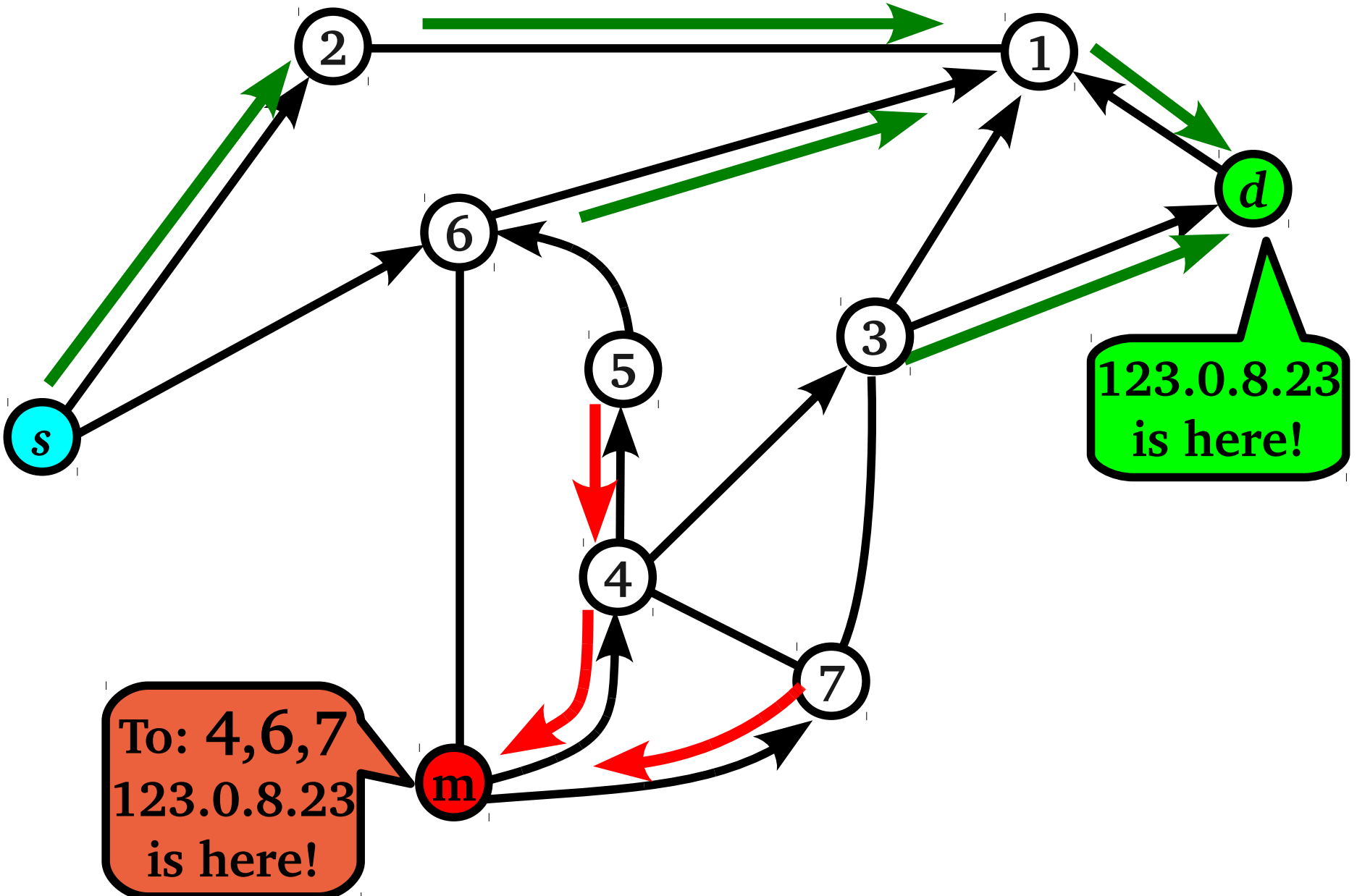
prefer customer rule



path (4 3 d) is disrupted by better class by path (4 m)



example of hijacking



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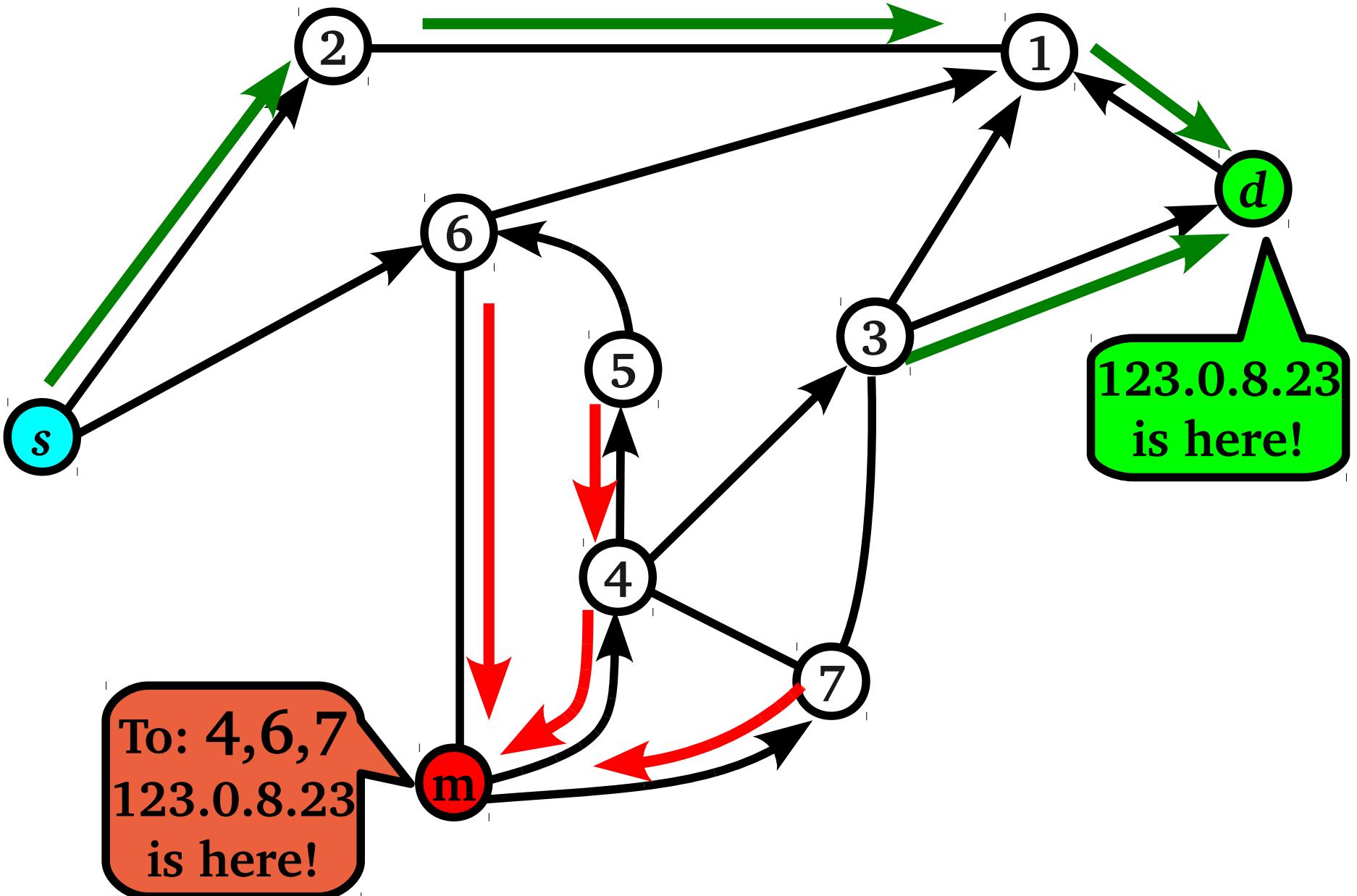

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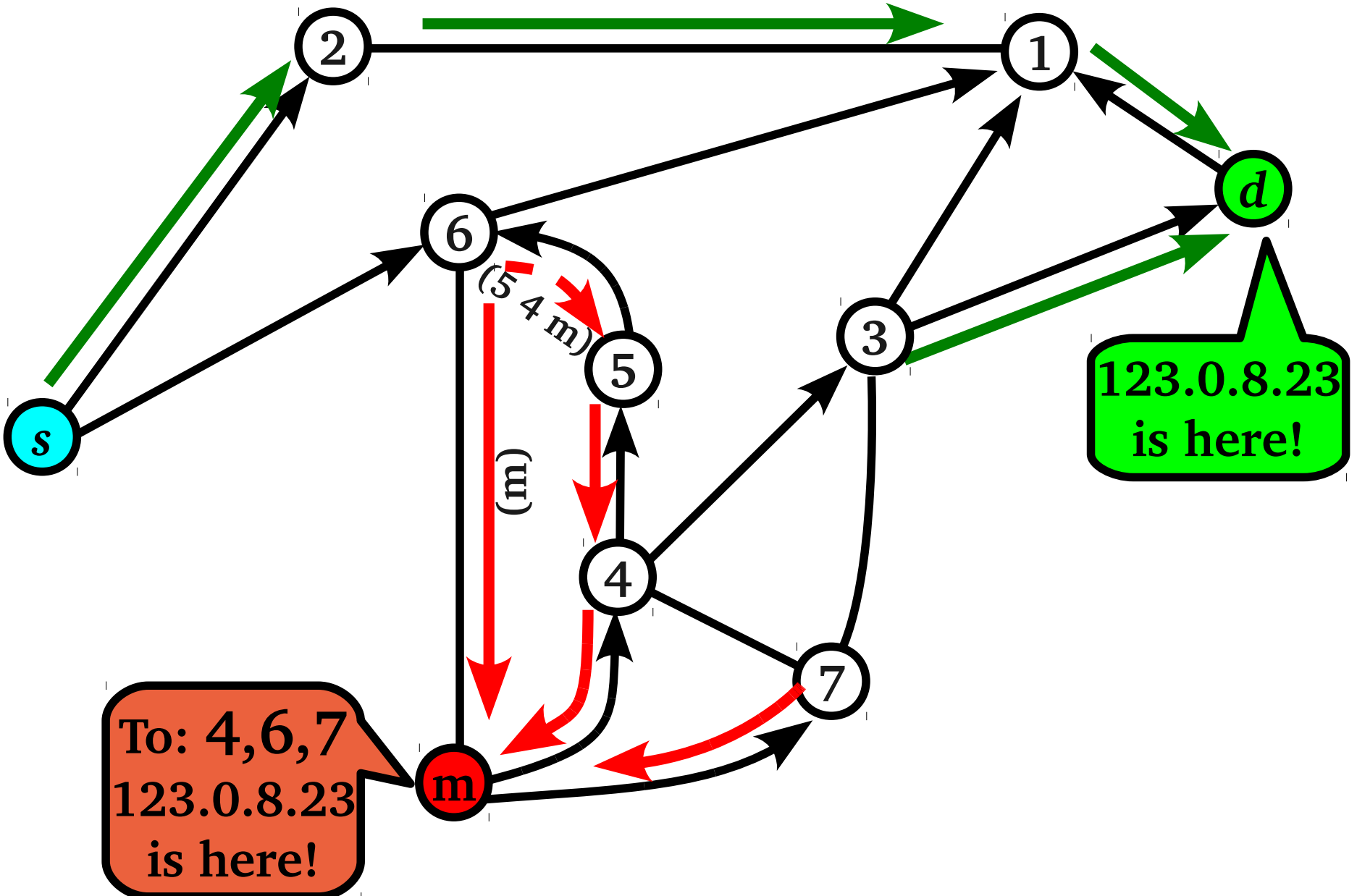

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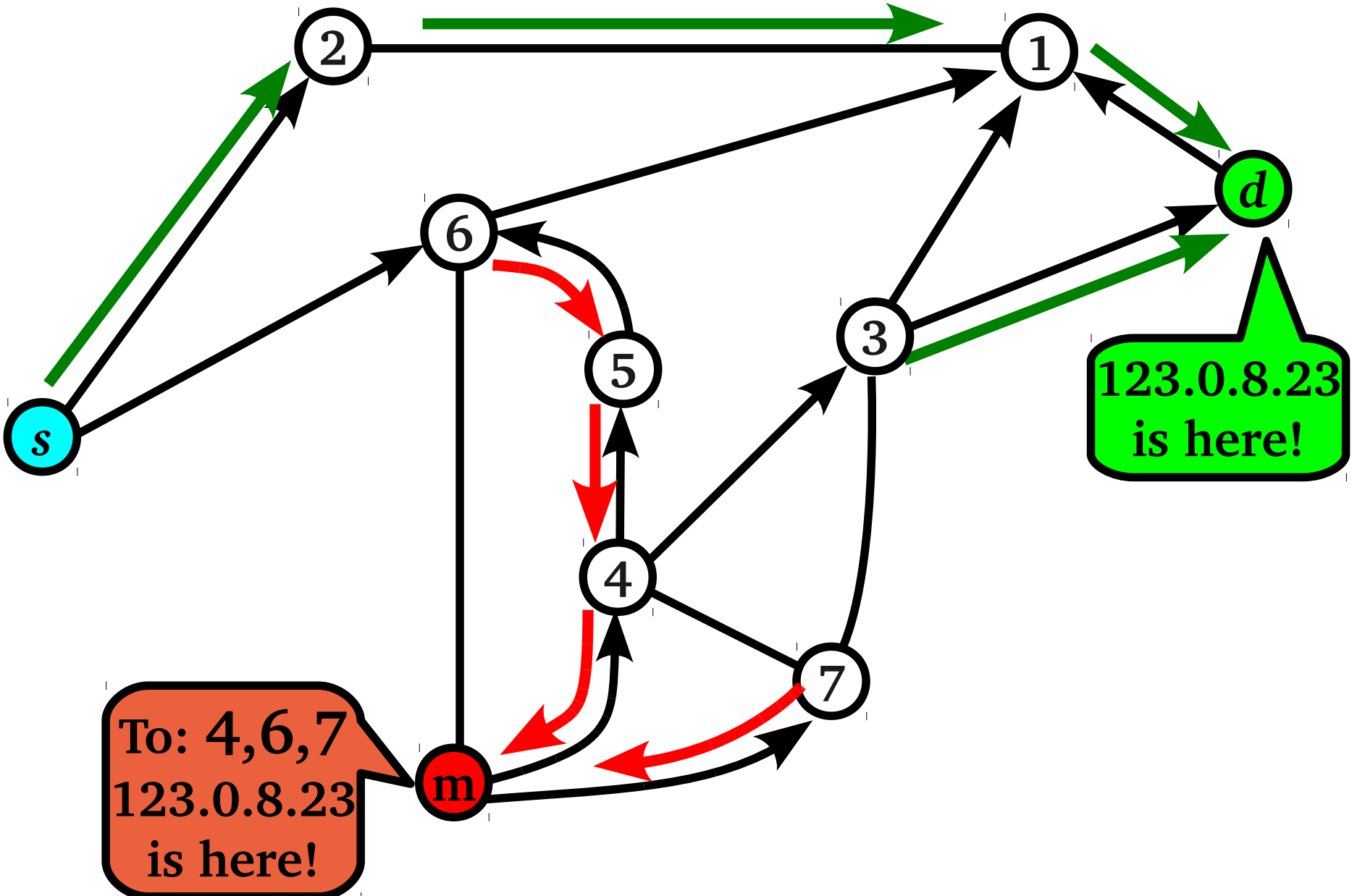
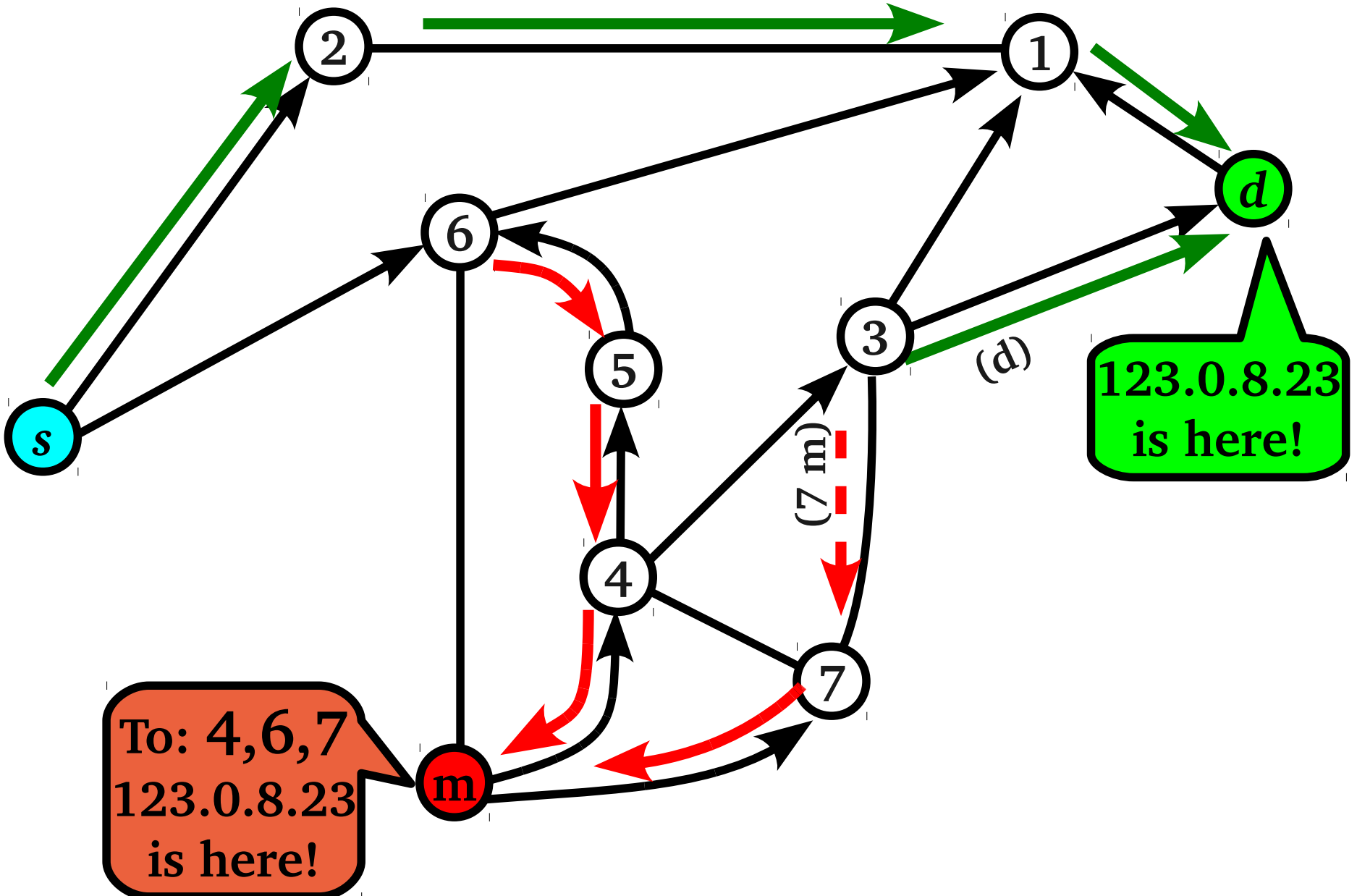
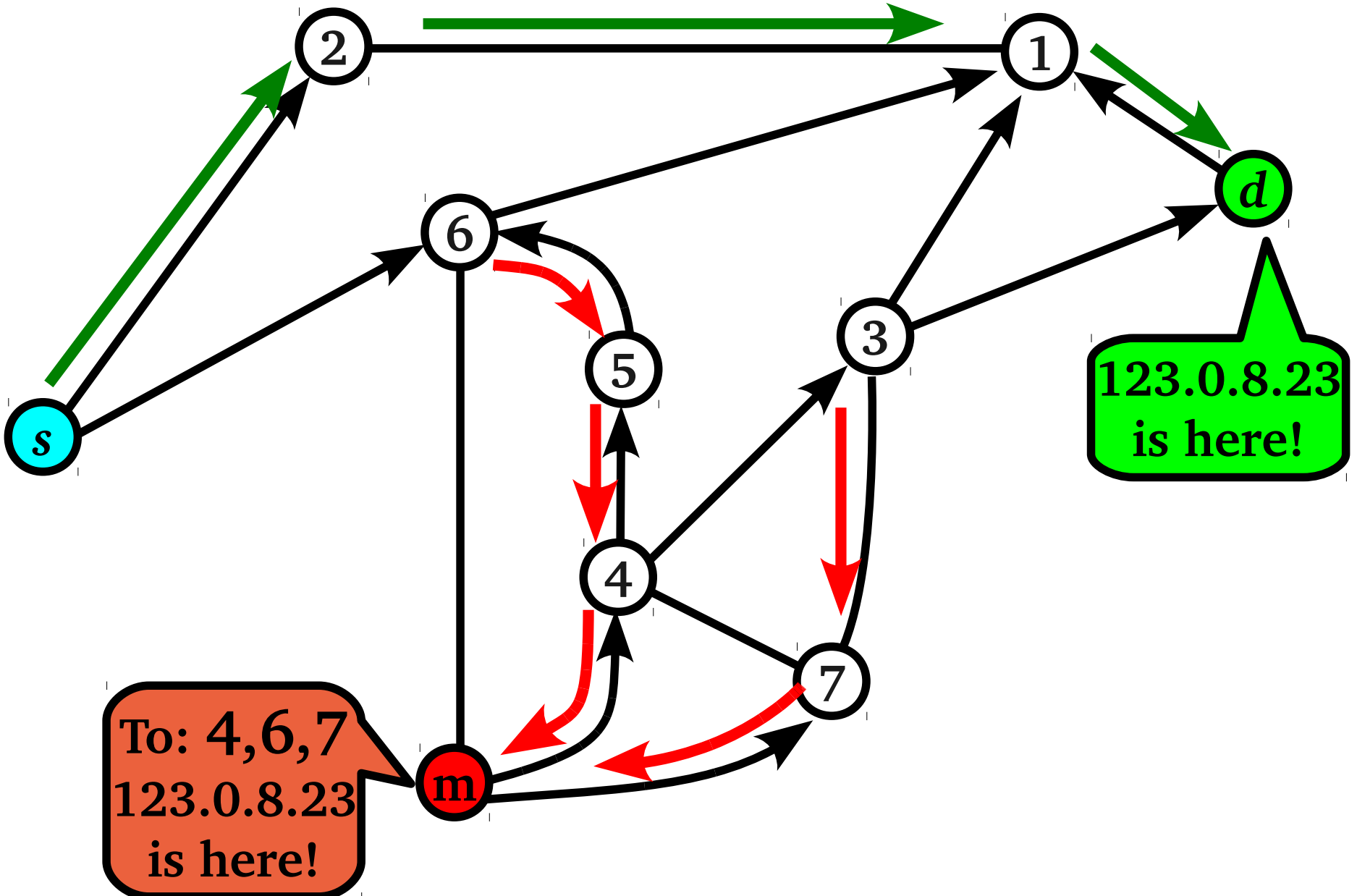


prefer peer rule



prefer peer rule



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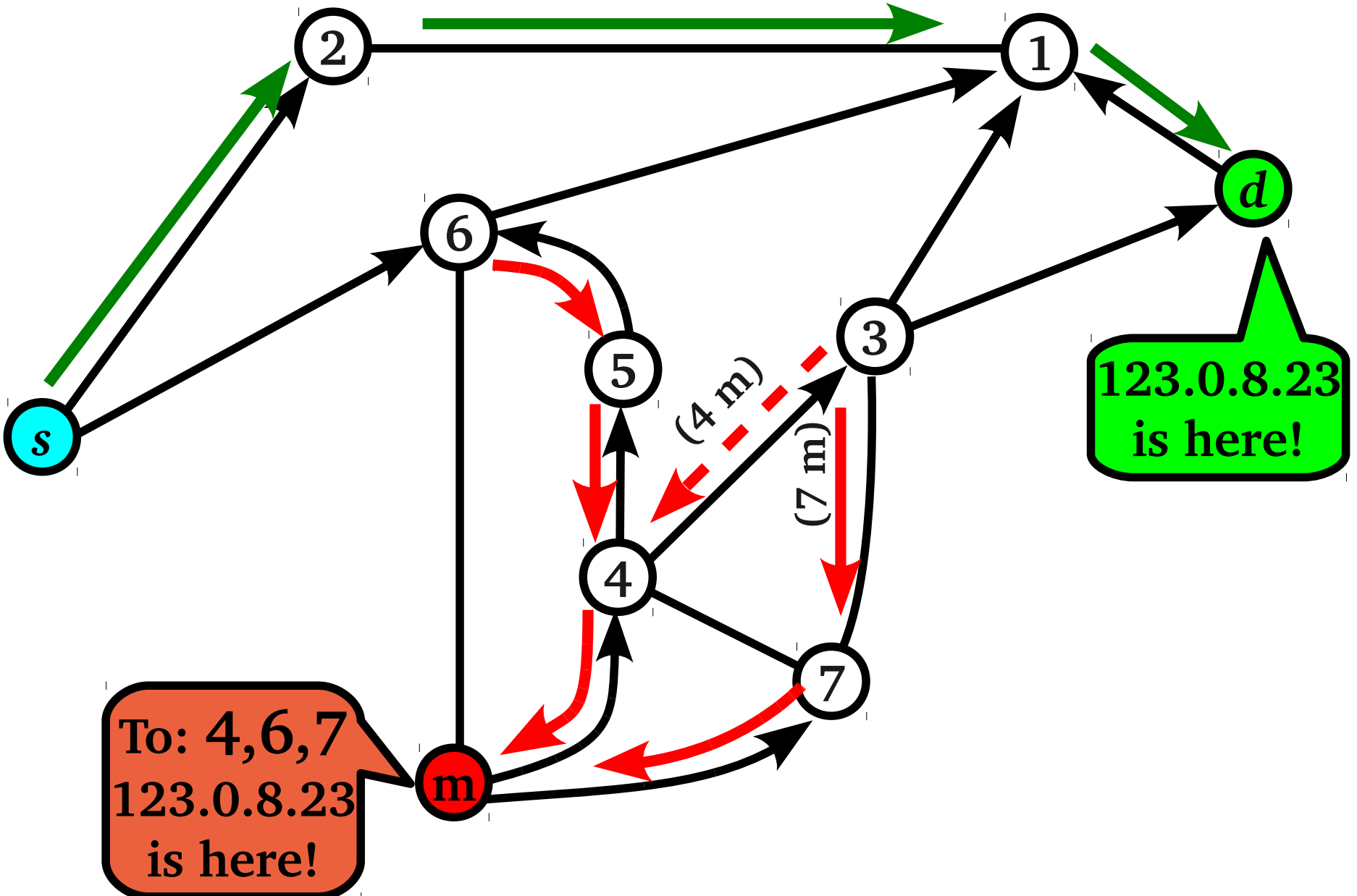

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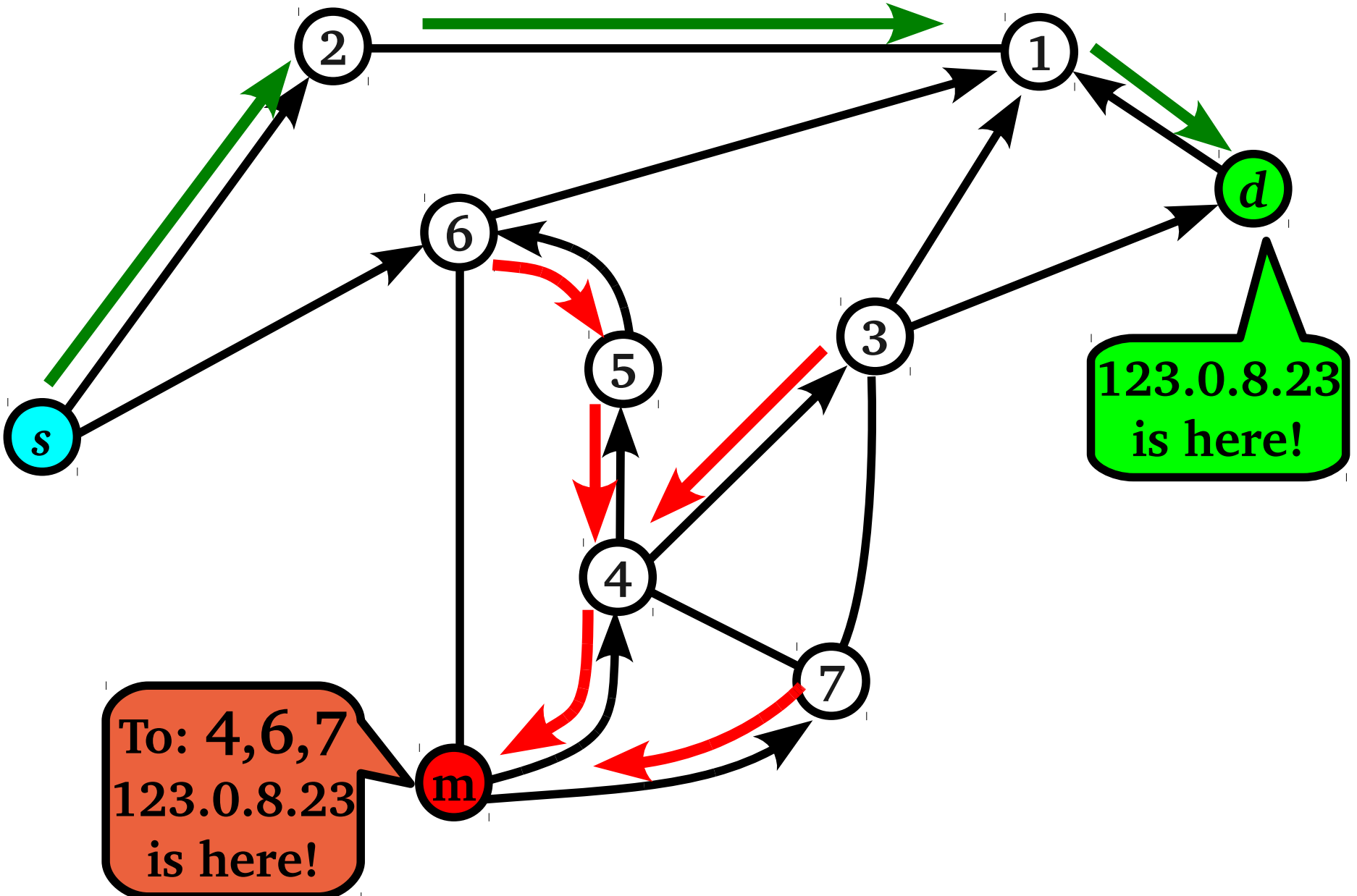
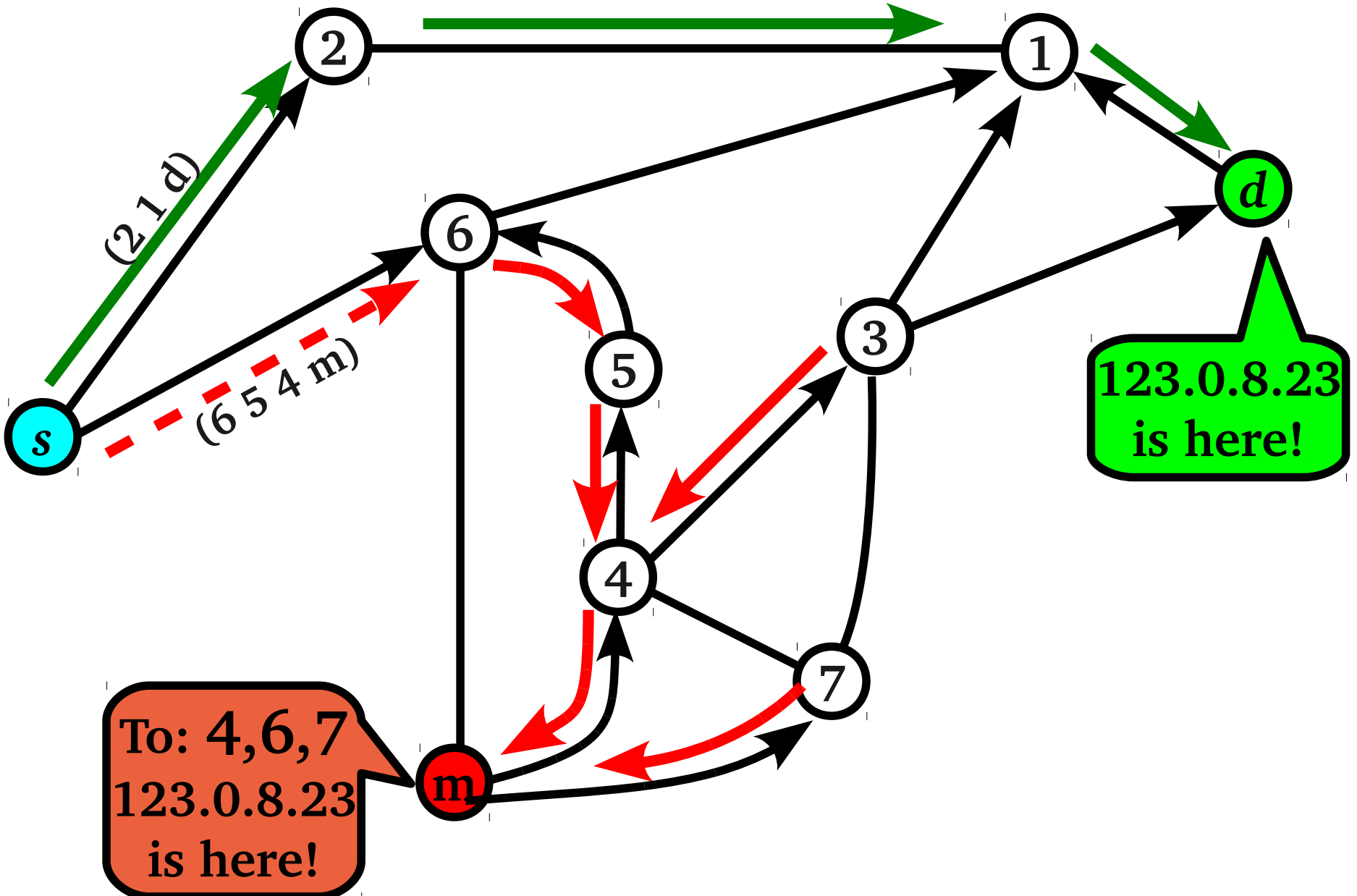
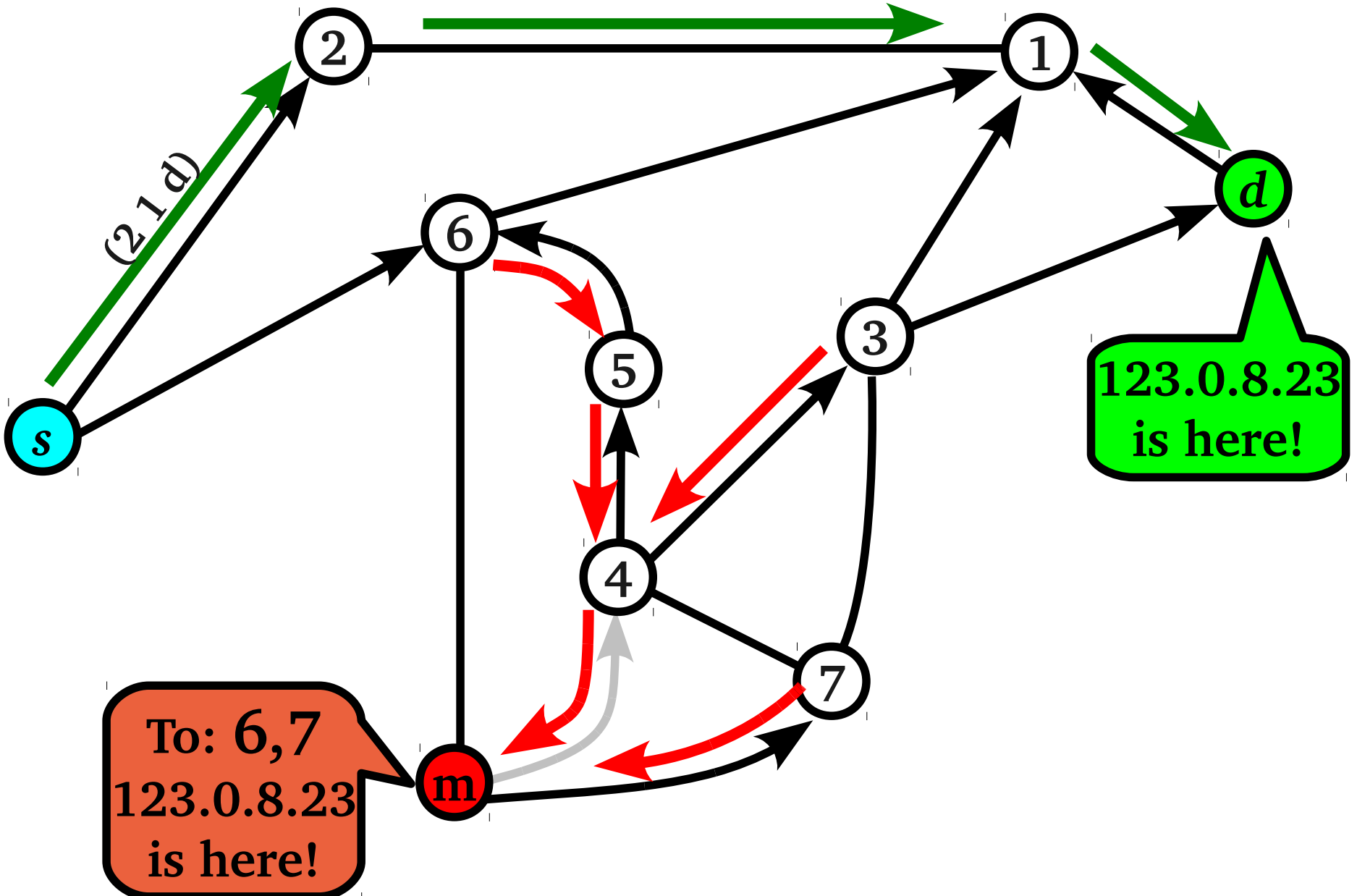


example of unsuccessful hijacking



example of hijacking:
announce to a subset of neighbors



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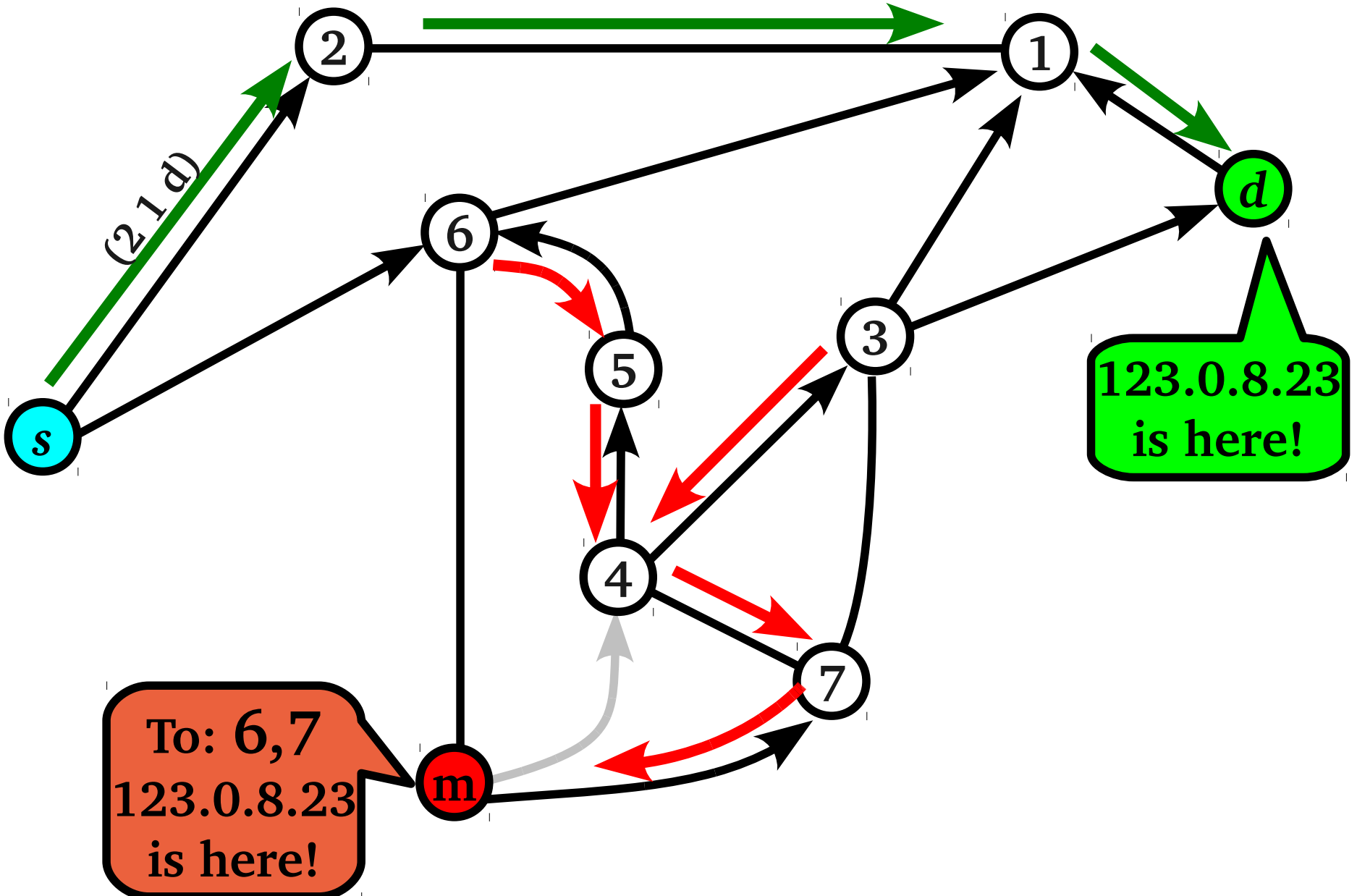

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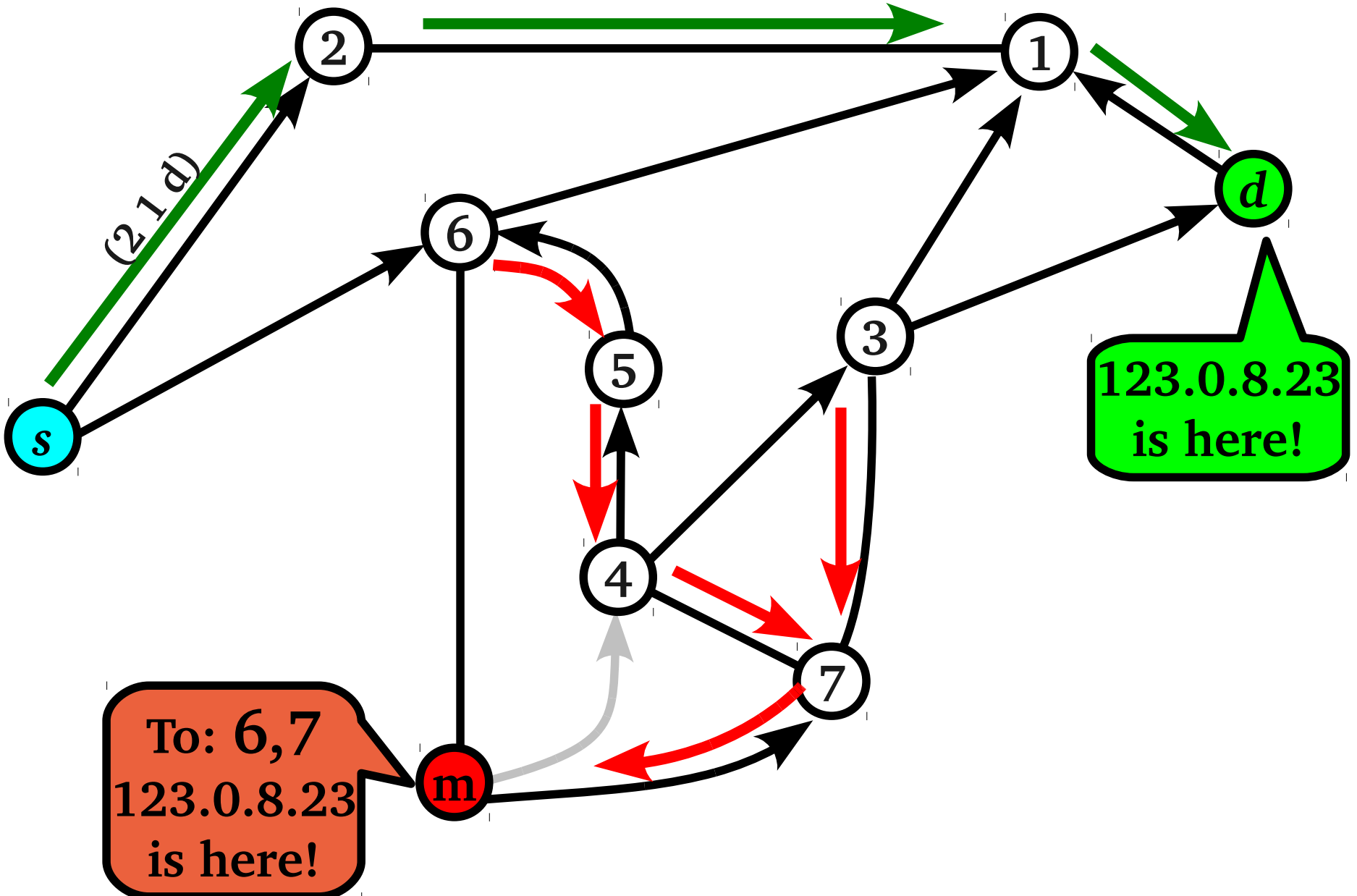

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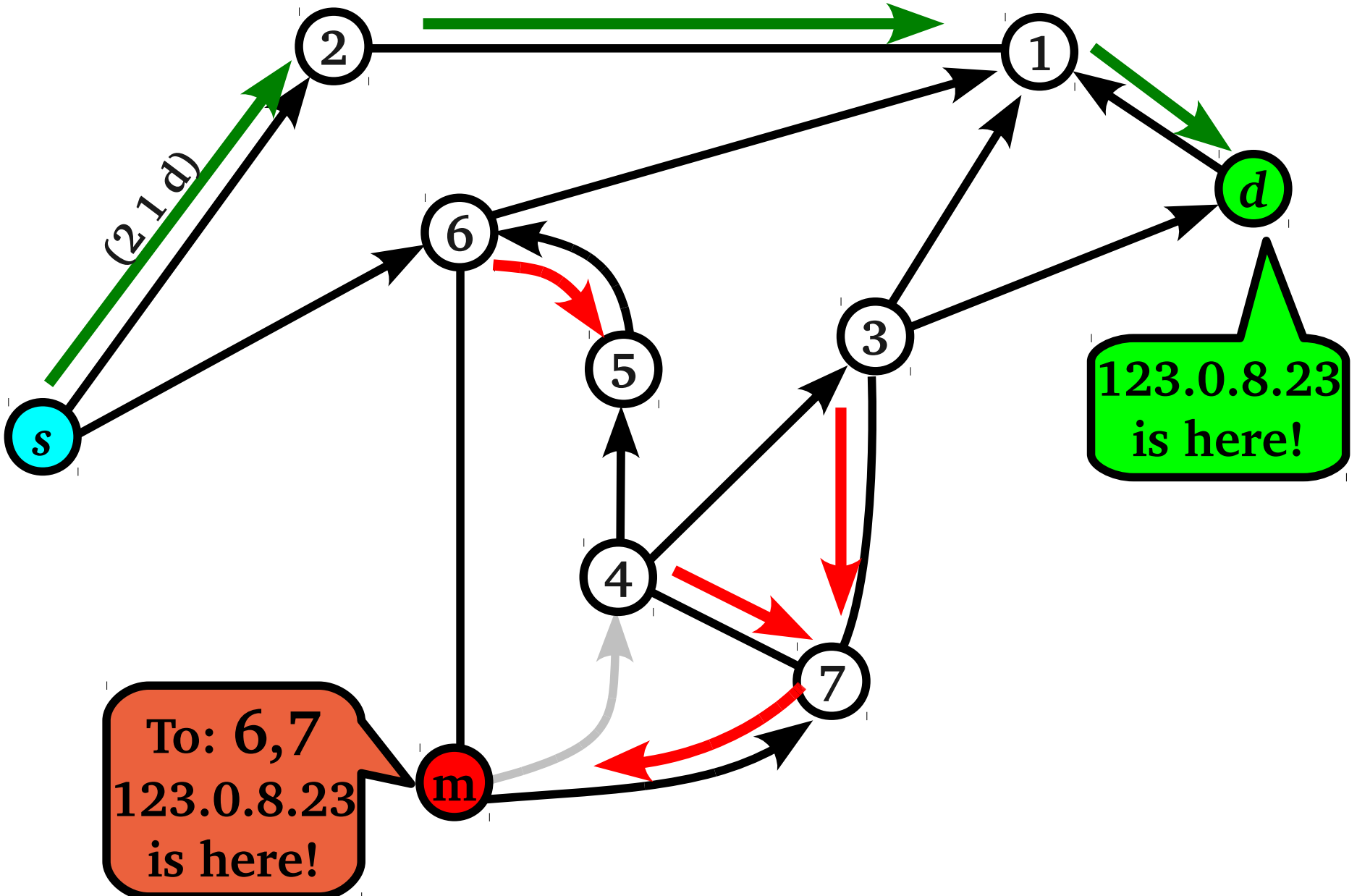

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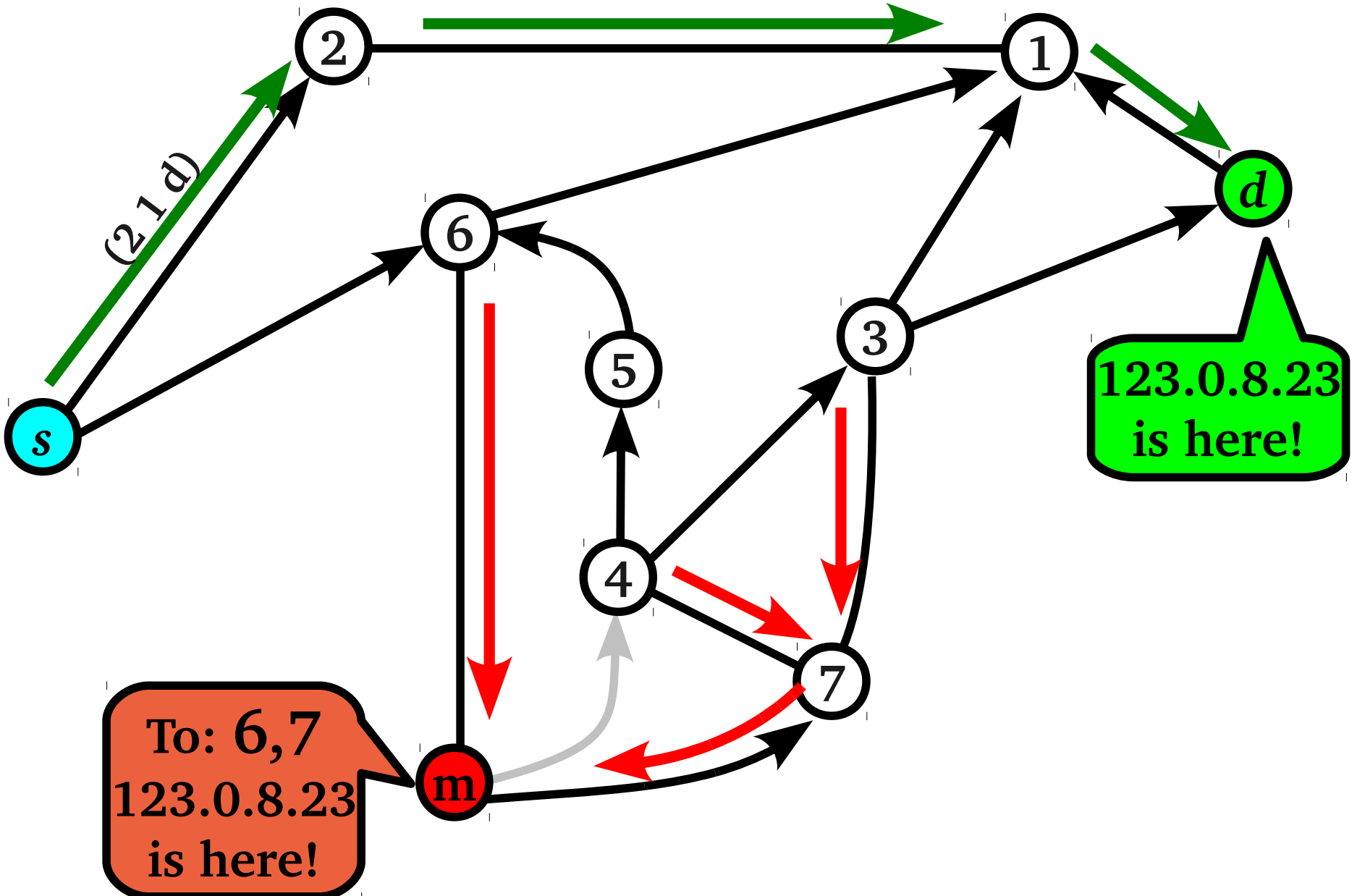

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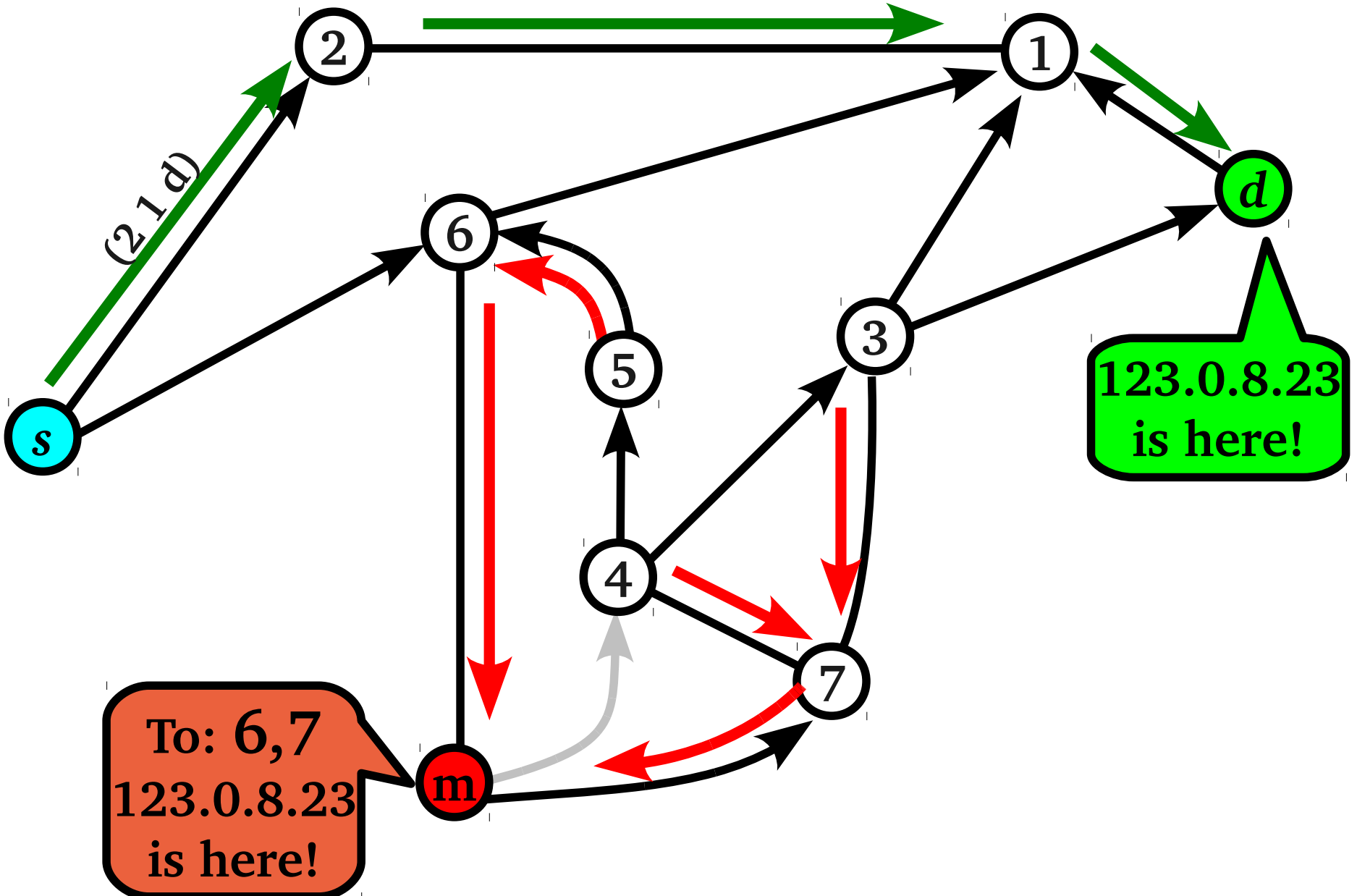

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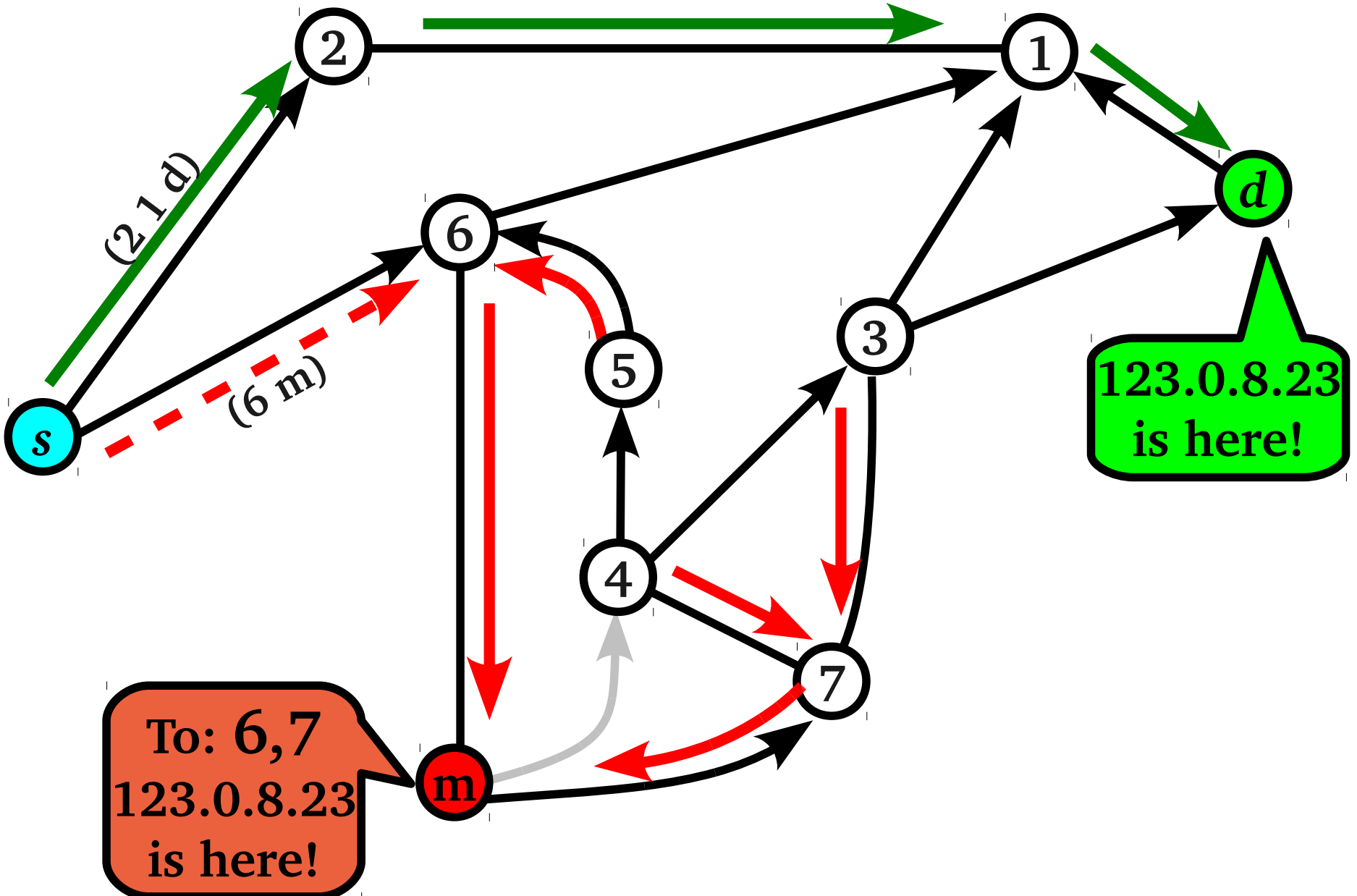
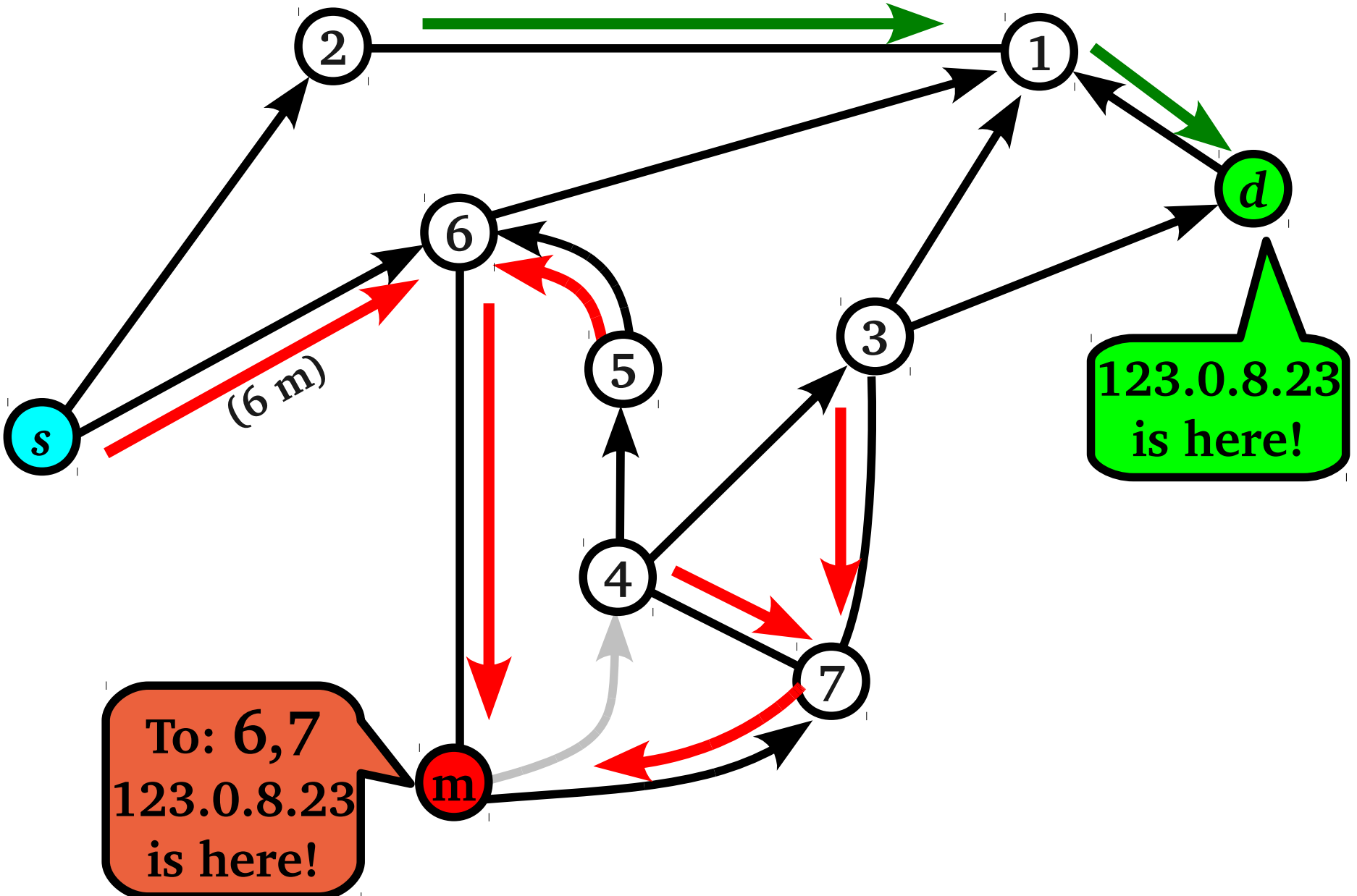
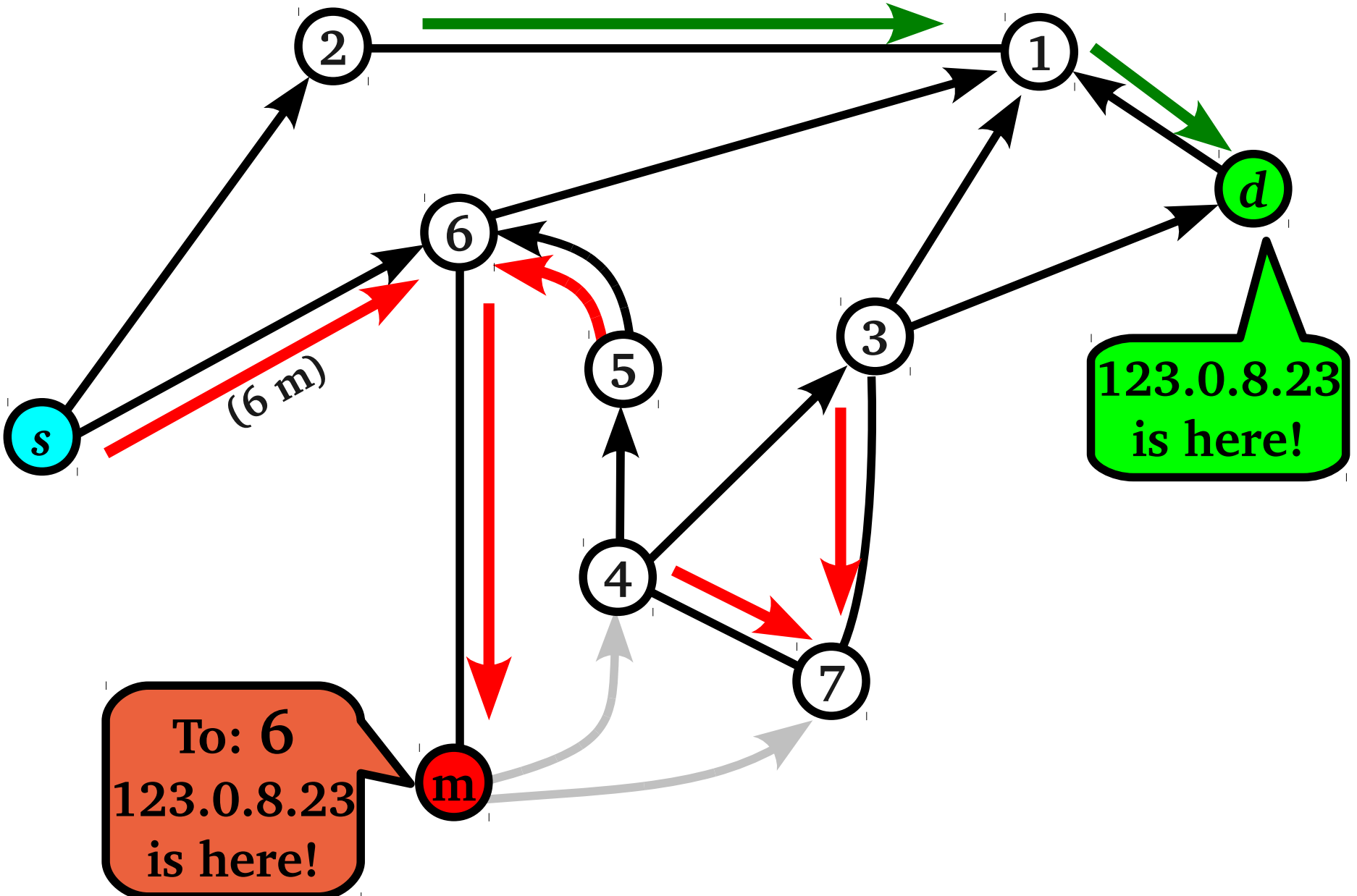
announce to a subset of neighbors



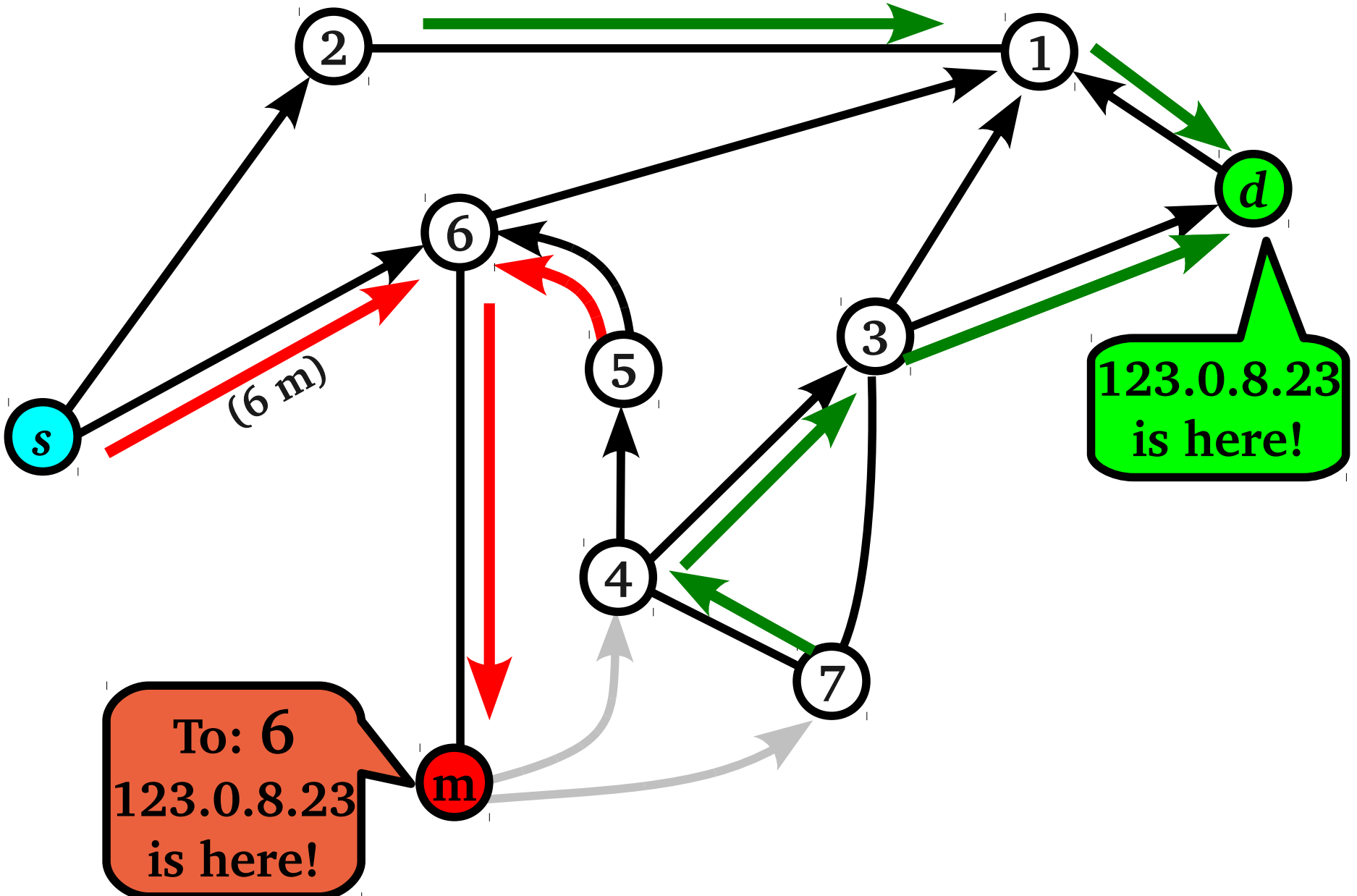
example of successful hijacking: announce to a subset of neighbors



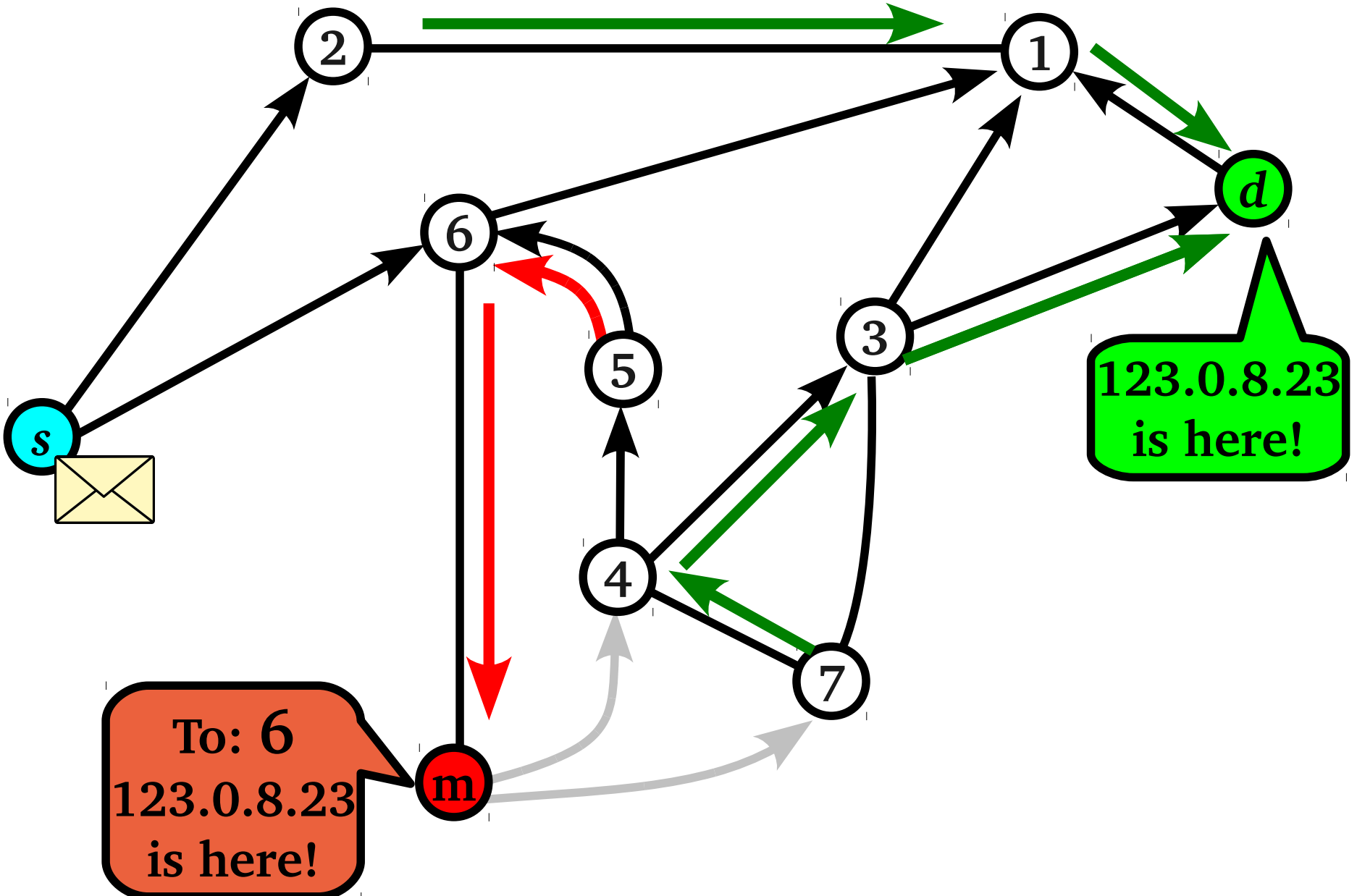
example of successful hijacking: announce to a subset of neighbors



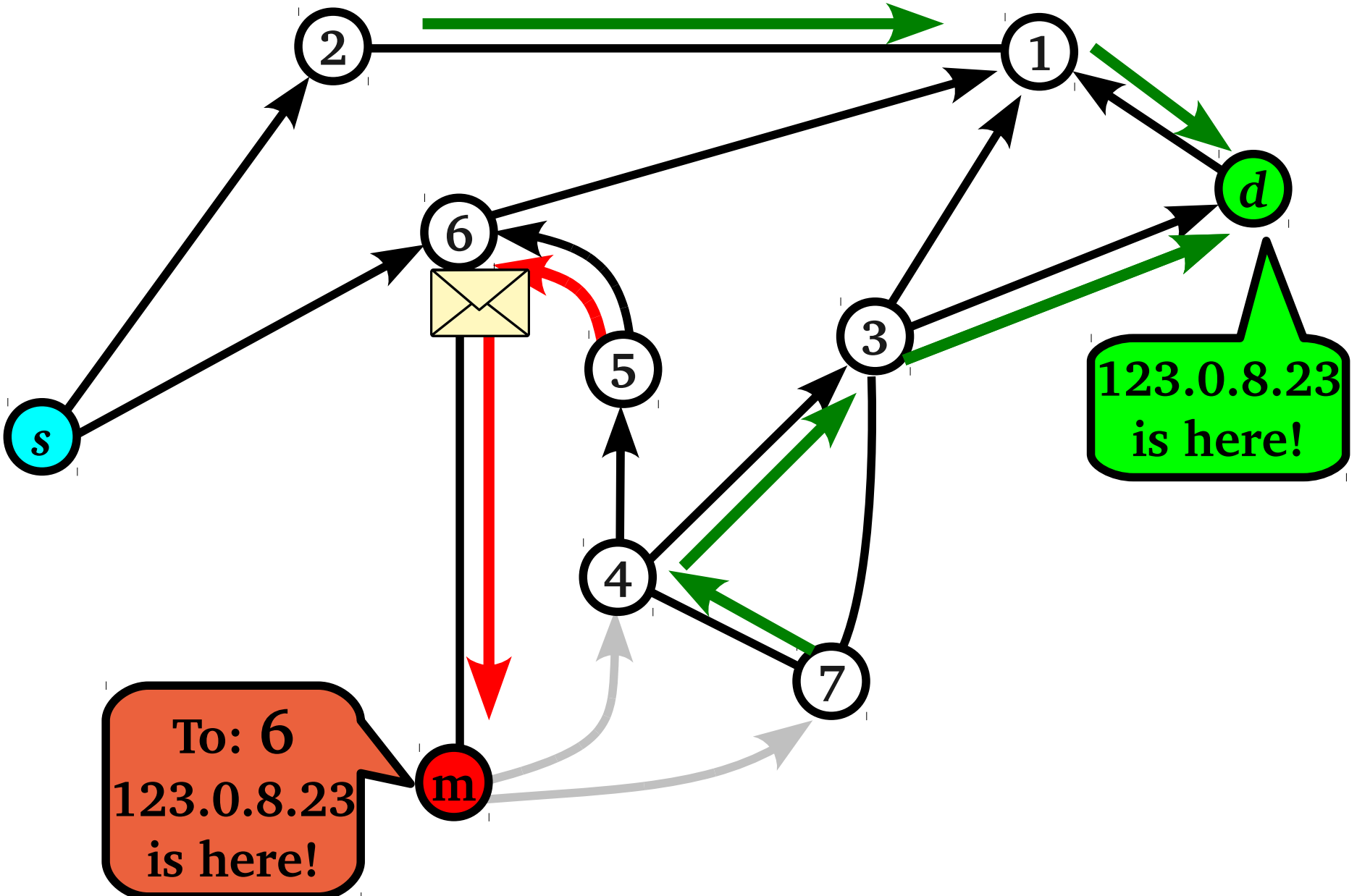
example of a successful interception



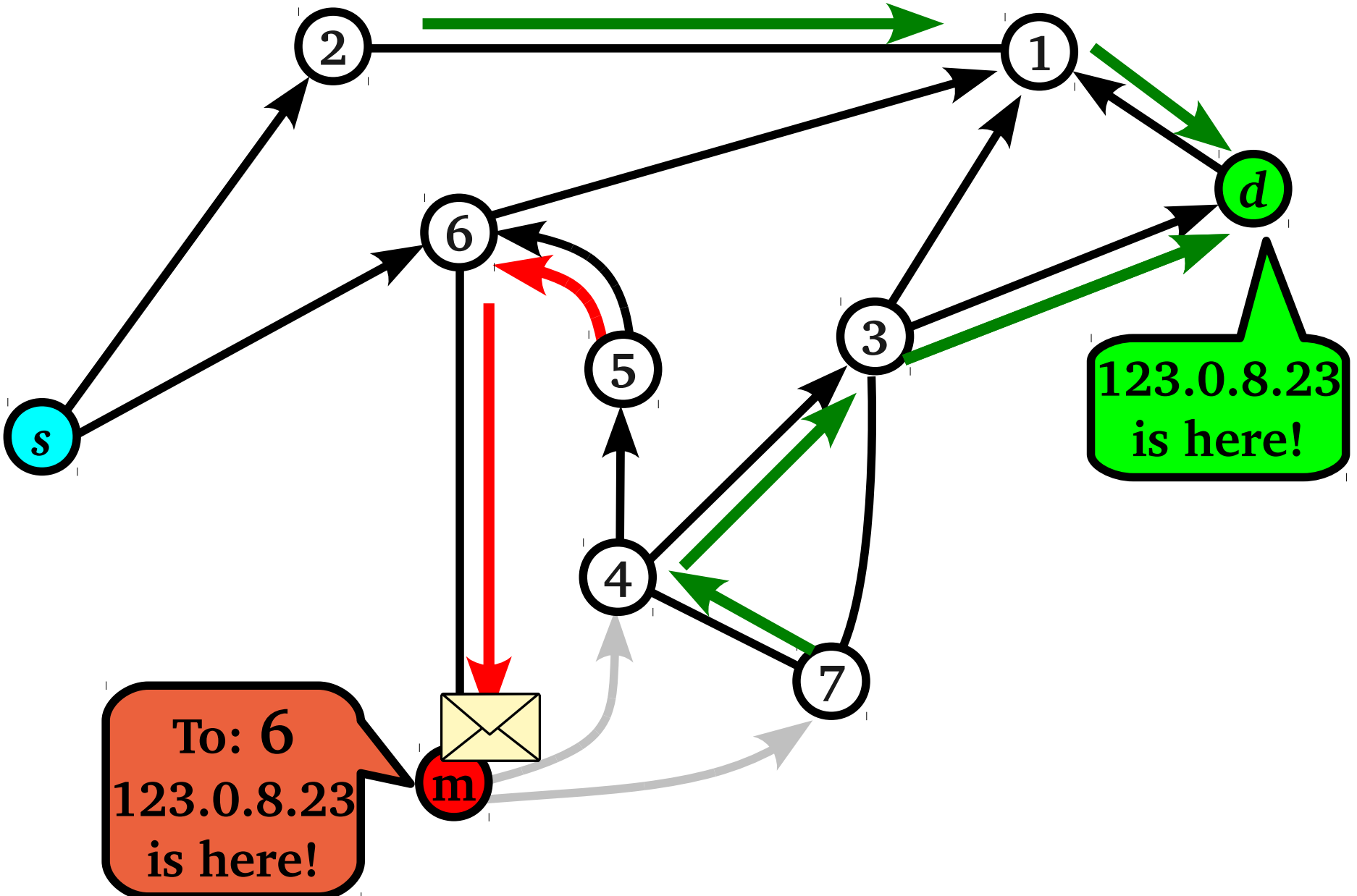
example of a successful interception



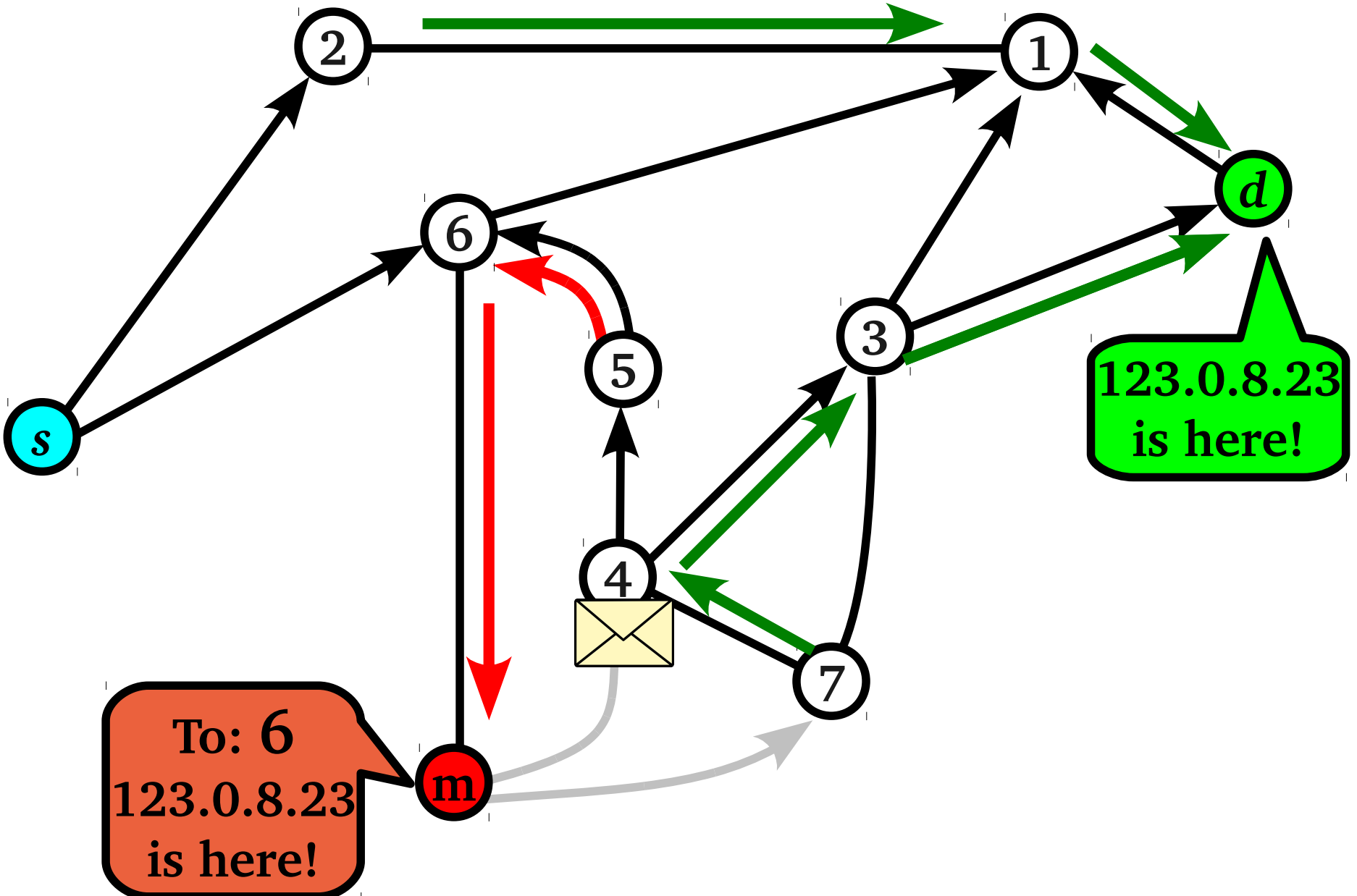
example of a successful interception



example of a successful interception



example of a successful interception



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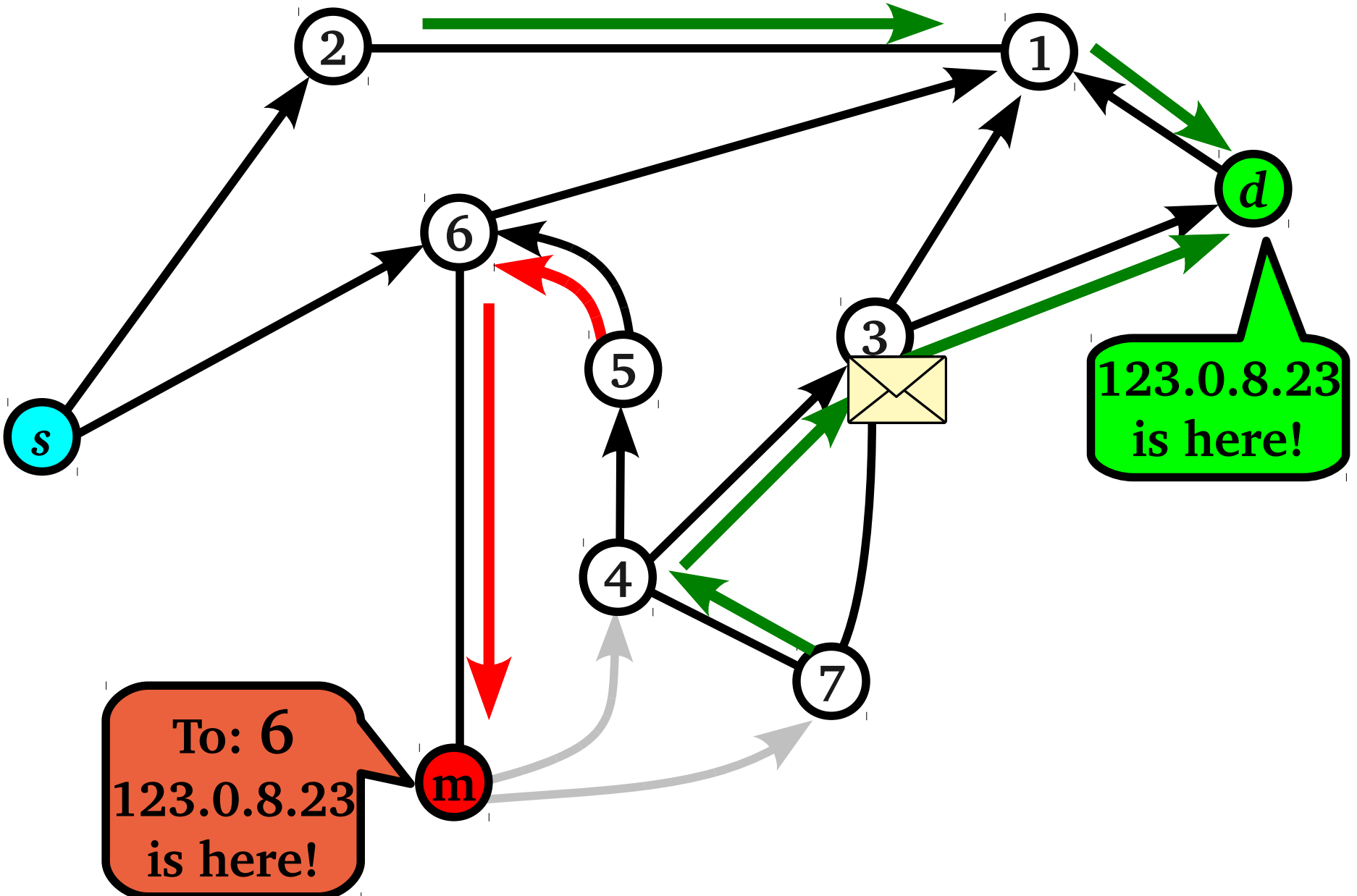

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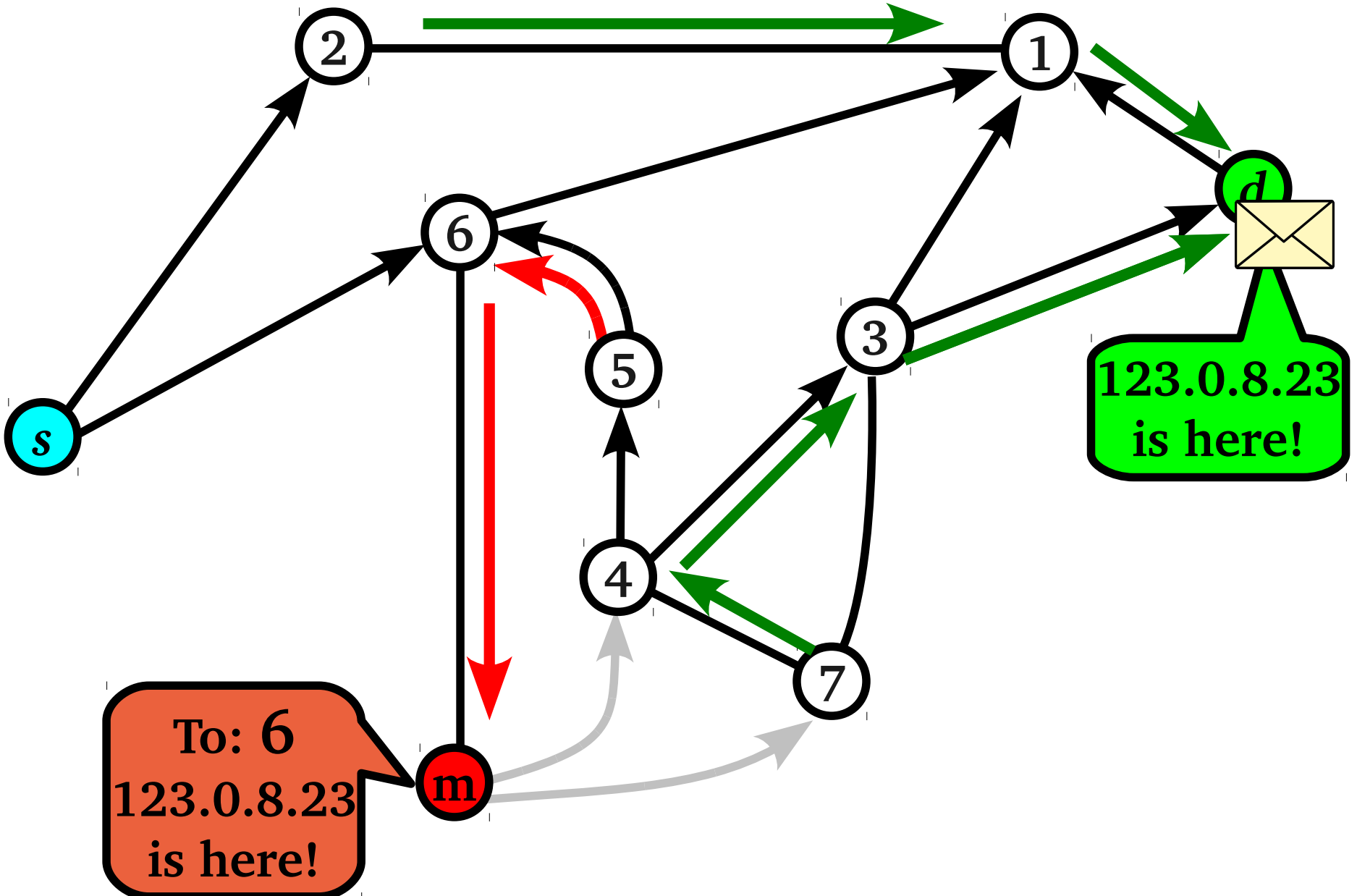


cheating capabilities of the manipulator

origin-spoofing cheating capabilities:

- a router can only pretend to be the origin of an arbitrary IP prefix.

cheating capabilities of the manipulator

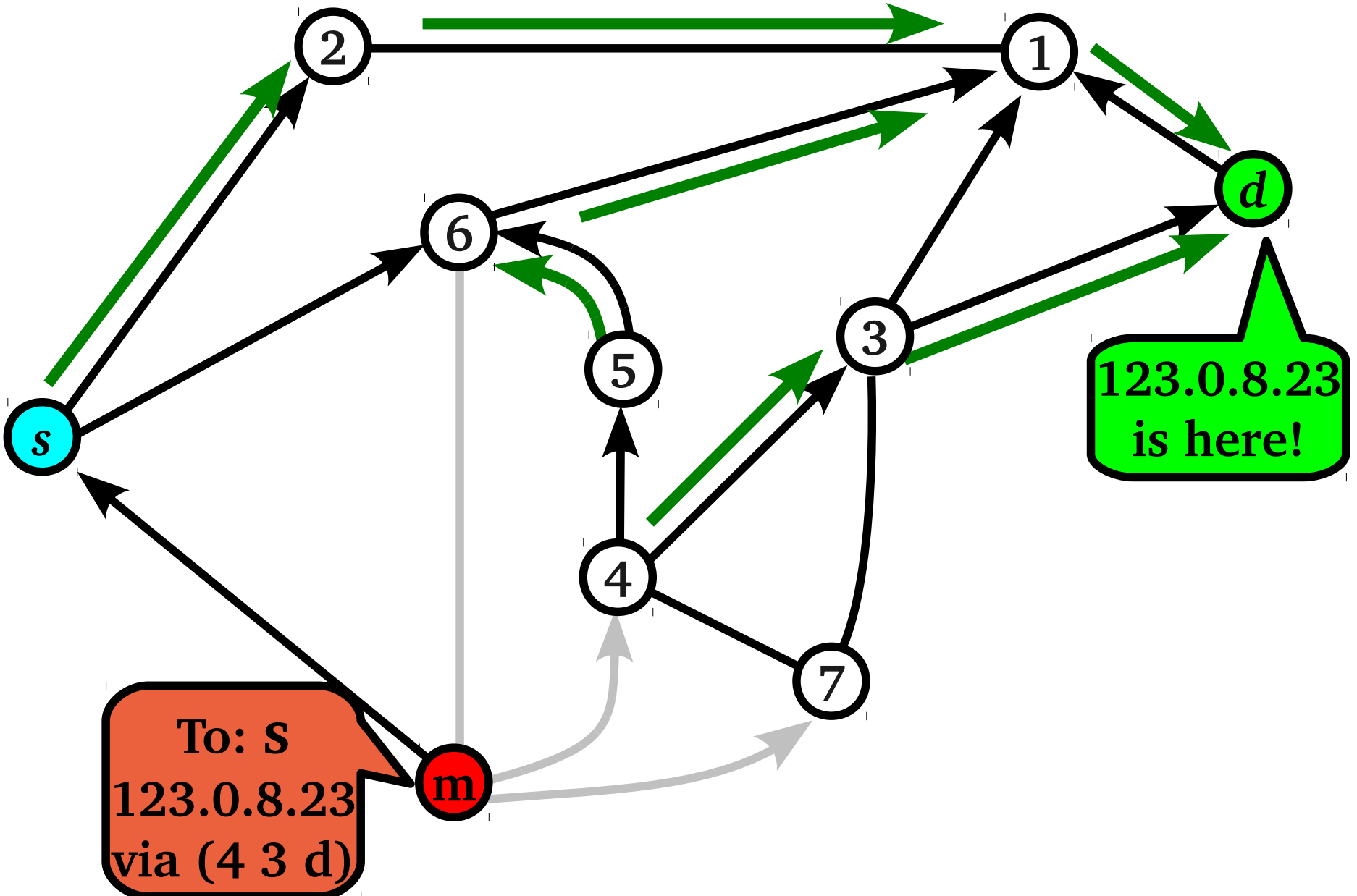
origin-spoofing cheating capabilities:

- a router can only pretend to be the origin of an arbitrary IP prefix.

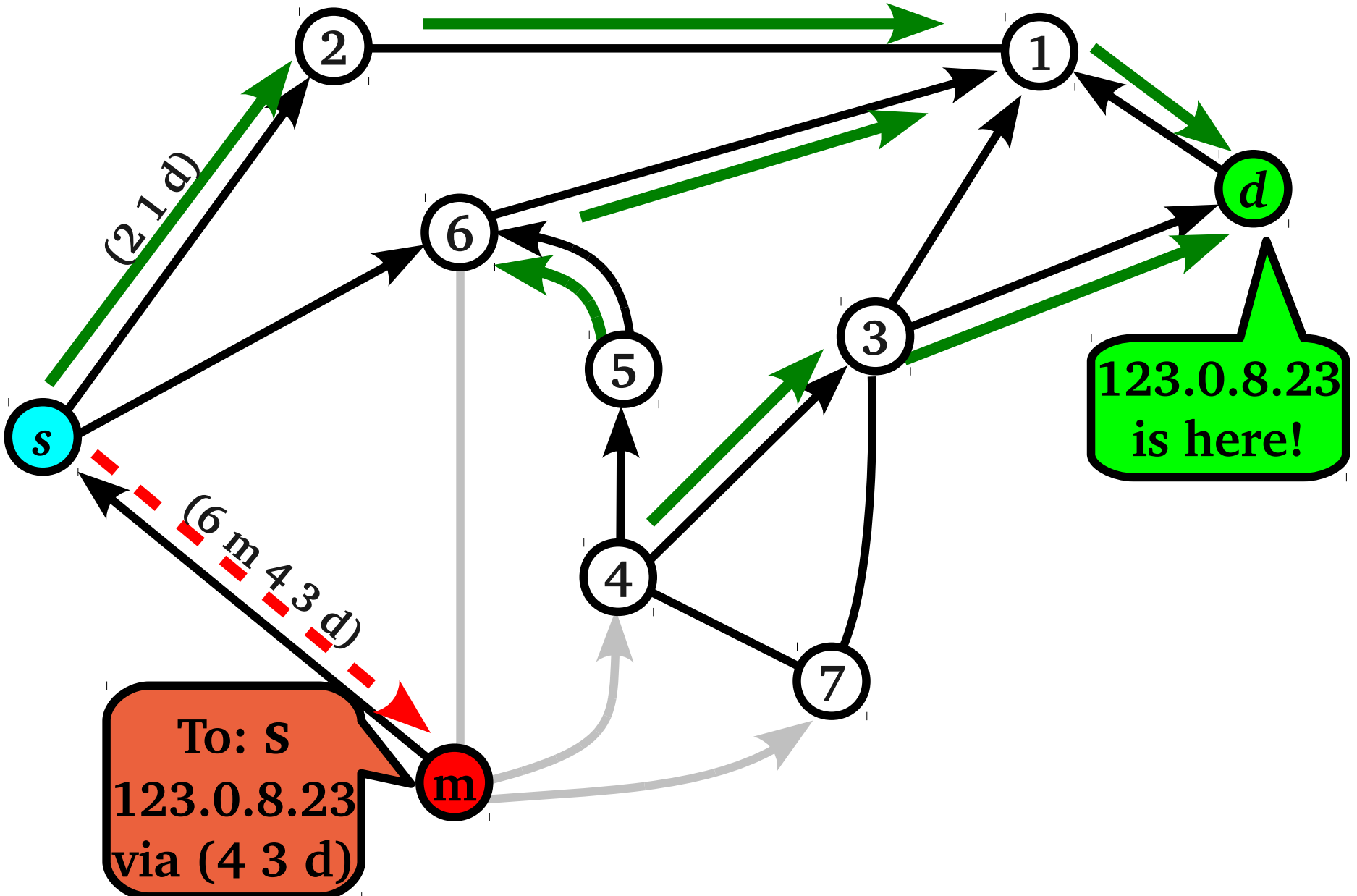
S-BGP cheating capabilities:

- a router cannot pretend to be the origin of an IP prefix that does not own.
- a router ***v*** can announce a path ***(v u)P*** only if ***u*** announced ***P*** to **v** in the past.

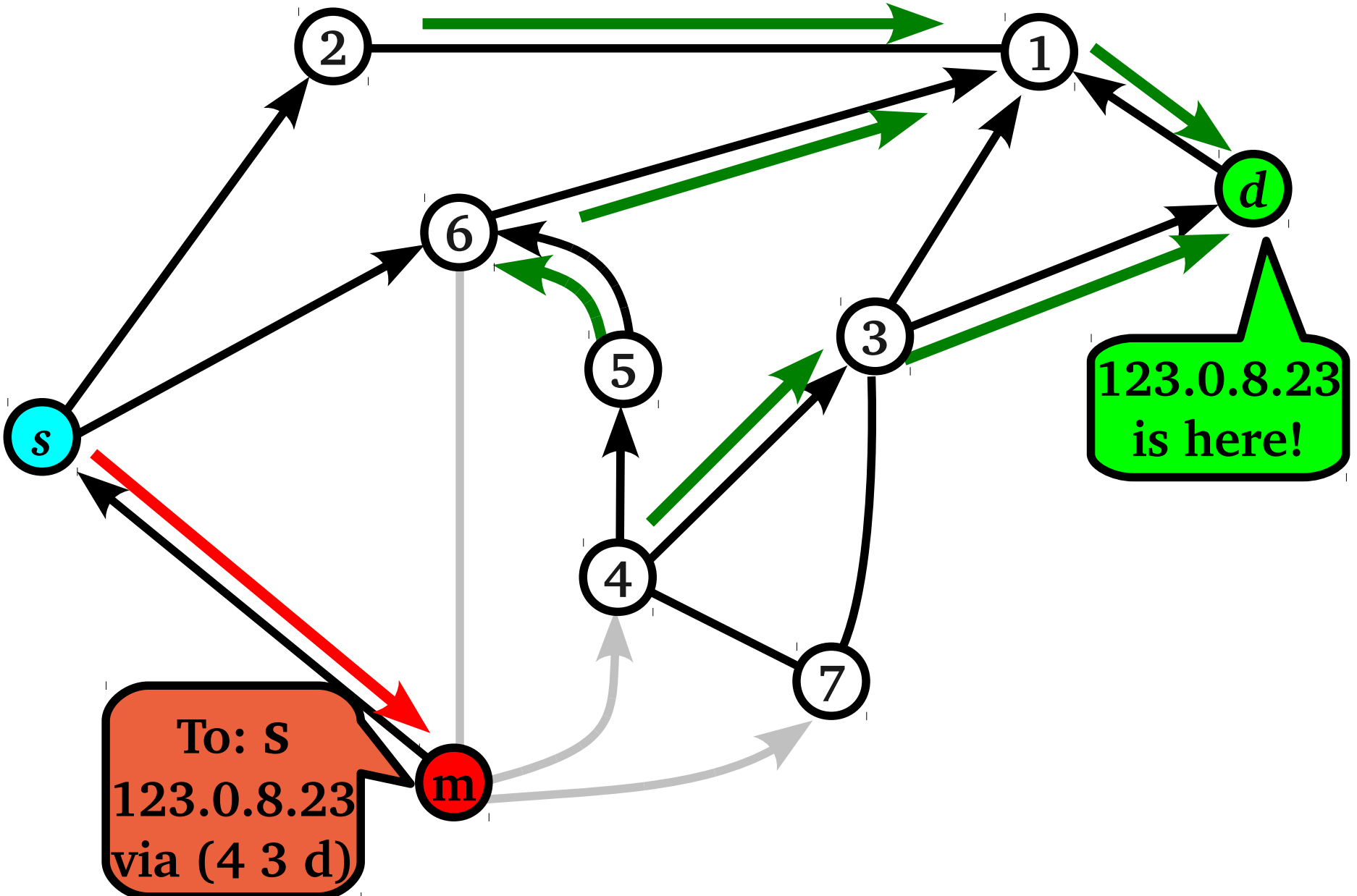
example of hijacking in S-BGP



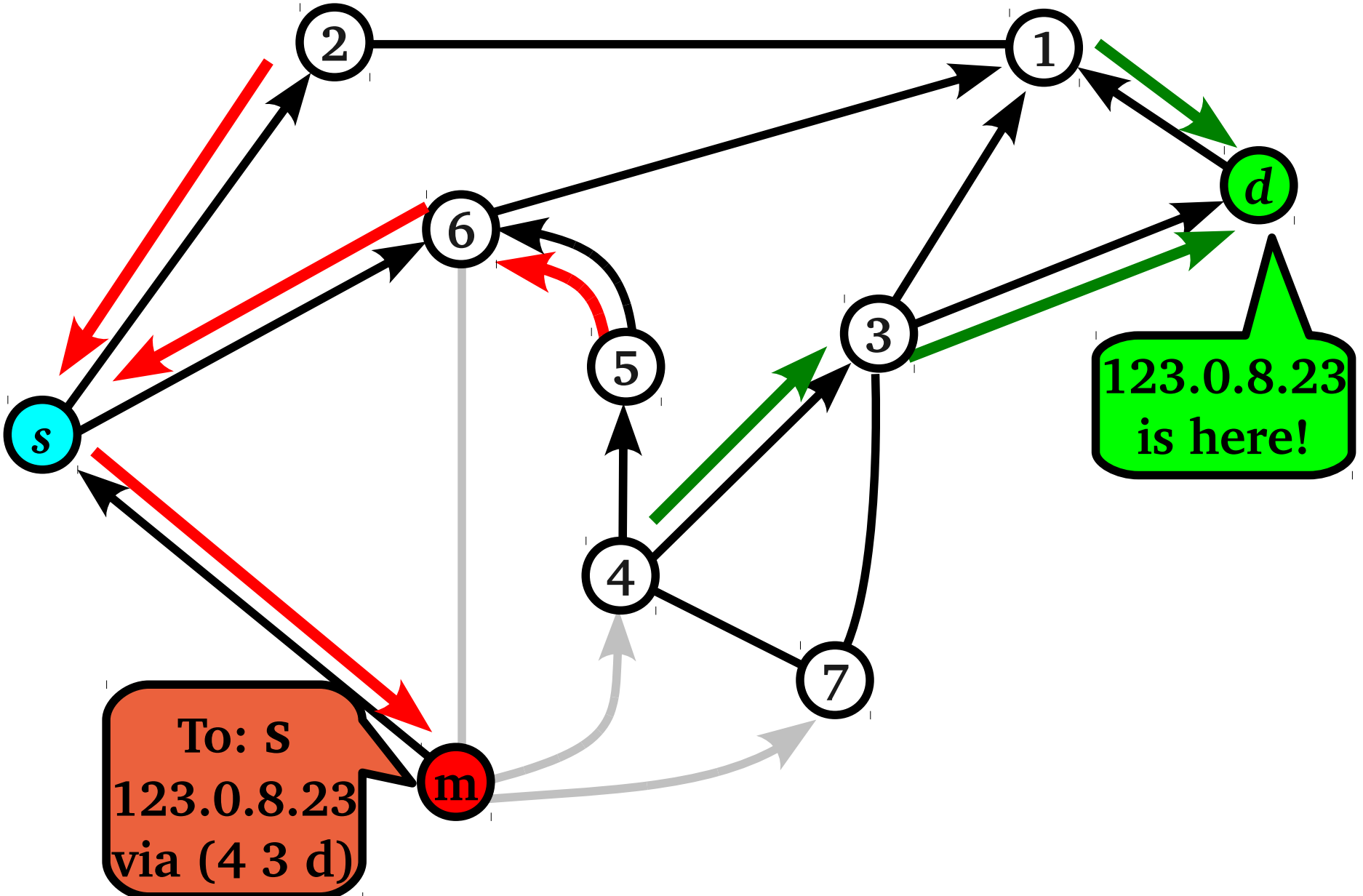
example of hijacking in S-BGP



example of hijacking in S-BGP



example of hijacking in S-BGP … and interception



related work

- Golberg Schapira Hummon Rexford, 2010
  - conjecture: is every hijack attack also an interception attack in S-BGP?
  - maximize traffic attraction is NP-hard
- Ballani Francis Zhang., 2007
  - methodology to intercept traffic + experimental study
- Levin Schapira Zohar, 2008
  - for several utility functions S-BGP is incentive compatible

our results (1)

- Golberg Schapira Hummon Rexford, 2010
  - is every hijack attack also an interception attack in S-BGP?

    Yes, it is! we'll discuss it later.

our results (2)

hijack problem. Given a BGP graph, a source, a destination, and a manipulator vertex, does there exist a strategy for **hijacking** the source vertex?

cheating capabilities	AS paths of any length	Bound AS-path length	Bound AS-path length and AS degree
origin-spoofing	**NP-hard**	**P**	P
S-BGP	NP-hard	**NP-Hard**	**P**

our results (2)

hijack problem. Given a BGP graph, a source, a destination, and a manipulator vertex, does there exist a strategy for **hijacking** the source vertex?

cheating capabilities	AS paths of any length	Bound AS-path length	Bound AS-path length and AS degree
origin-spoofing	NP-hard	**P**	P
S-BGP	NP-hard	**NP-Hard**	P

marks a sharp difference between BGP and S-BGP

hijack with origin-spoofing capabilities is in P

Theorem. If

- manipulator has origin-spoofing cheating capabilities and
- the length of the longest valley-free path is bounded by a constant,

then problem *hijack* is solvable in polynomial time.

hijack with origin-spoofing capabilities is in P (proof)

Hijack Algorithm.

input:

- BGP graph
- destination d, source s, manipulator m

output:

- a set A of neighbors of m

hijack with origin-spoofing capabilities is in P (proof)

Hijack Algorithm.

1: for each valley-free path p_{sm} from s to m

hijack with origin-spoofing capabilities is in P (proof)

Hijack Algorithm.

1: for each valley-free path p_{sm} from s to m

2: A = a set containing the neighbor of m in p_{sm}

hijack with origin-spoofing capabilities is in P (proof)

Hijack Algorithm.

1: for each valley-free path p_{sm} from s to m
2: A = a set containing the neighbor of m in p_{sm}
3: for each neighbor n of m
4: if there is no valley-free path through (m,n) that disrupts p_{sm} by better class
5: add n to A

hijack with origin-spoofing capabilities is in P (proof)

Hijack Algorithm.

1: for each valley-free path p_{sm} from s to m
2: A = a set containing the neighbor of m in p_{sm}
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5: add n to A
6: if attack succeeds announcing to A
7: return A

hijack with origin-spoofing capabilities is in P (proof)

Hijack Algorithm.

1: for each valley-free path p_{sm} from s to m
2: A=a set containing the neighbor of m in p_{sm}
3: for each neighbor n of m
4: if there is no valley-free path through (m,n) that disrupts p_{sm} by better class
5: add n to A
6: if attack succeeds announcing to A
7: return A
8: return empty-set

hijack with origin-spoofing capabilities is in P (proof)

correctness:

6: if attack succeeds announcing to A

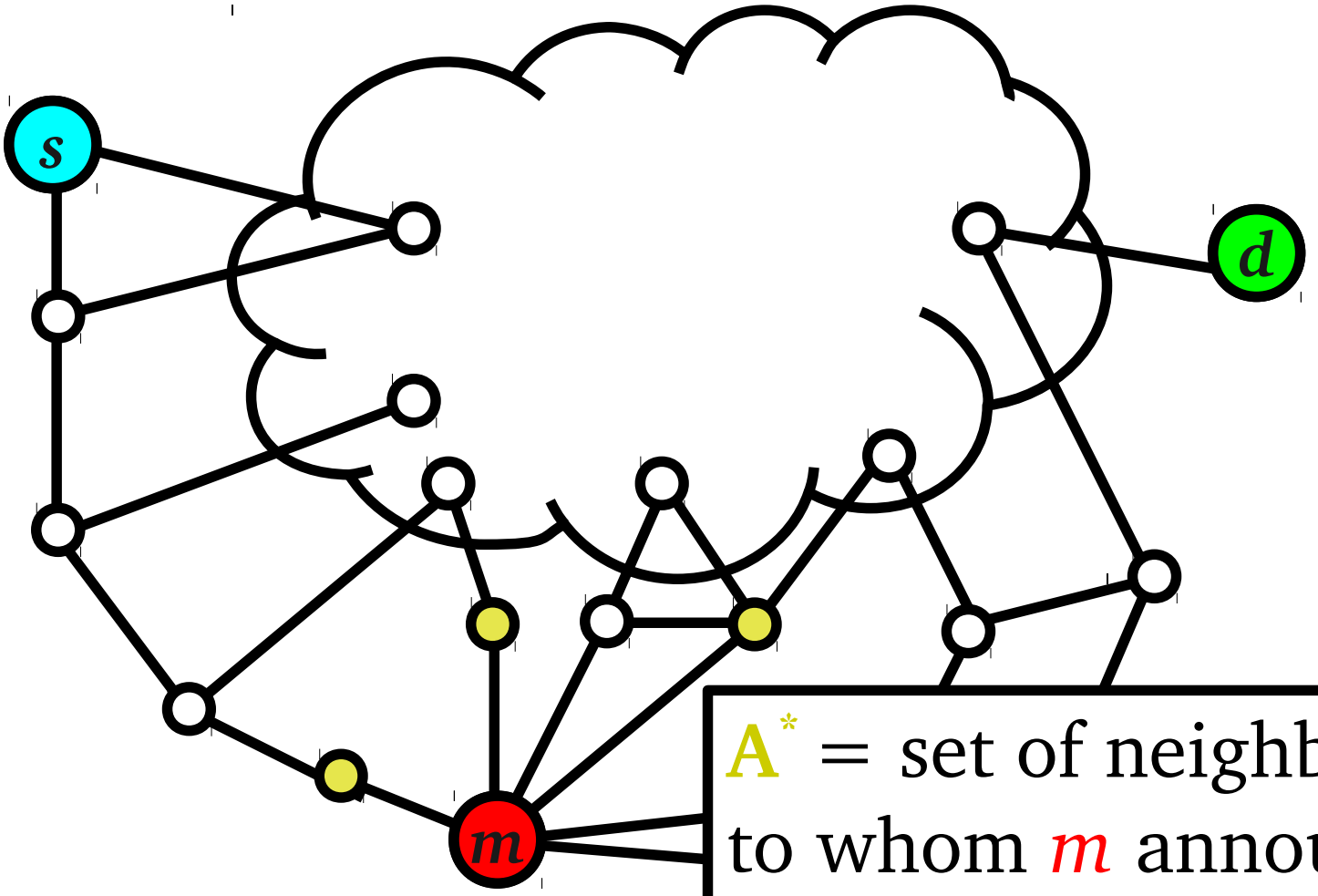
7: return A

completeness:

Suppose by contradiction there exists a successful attack strategy A^* from m but the Hijack Algorithm fails

algorithm completeness (proof)

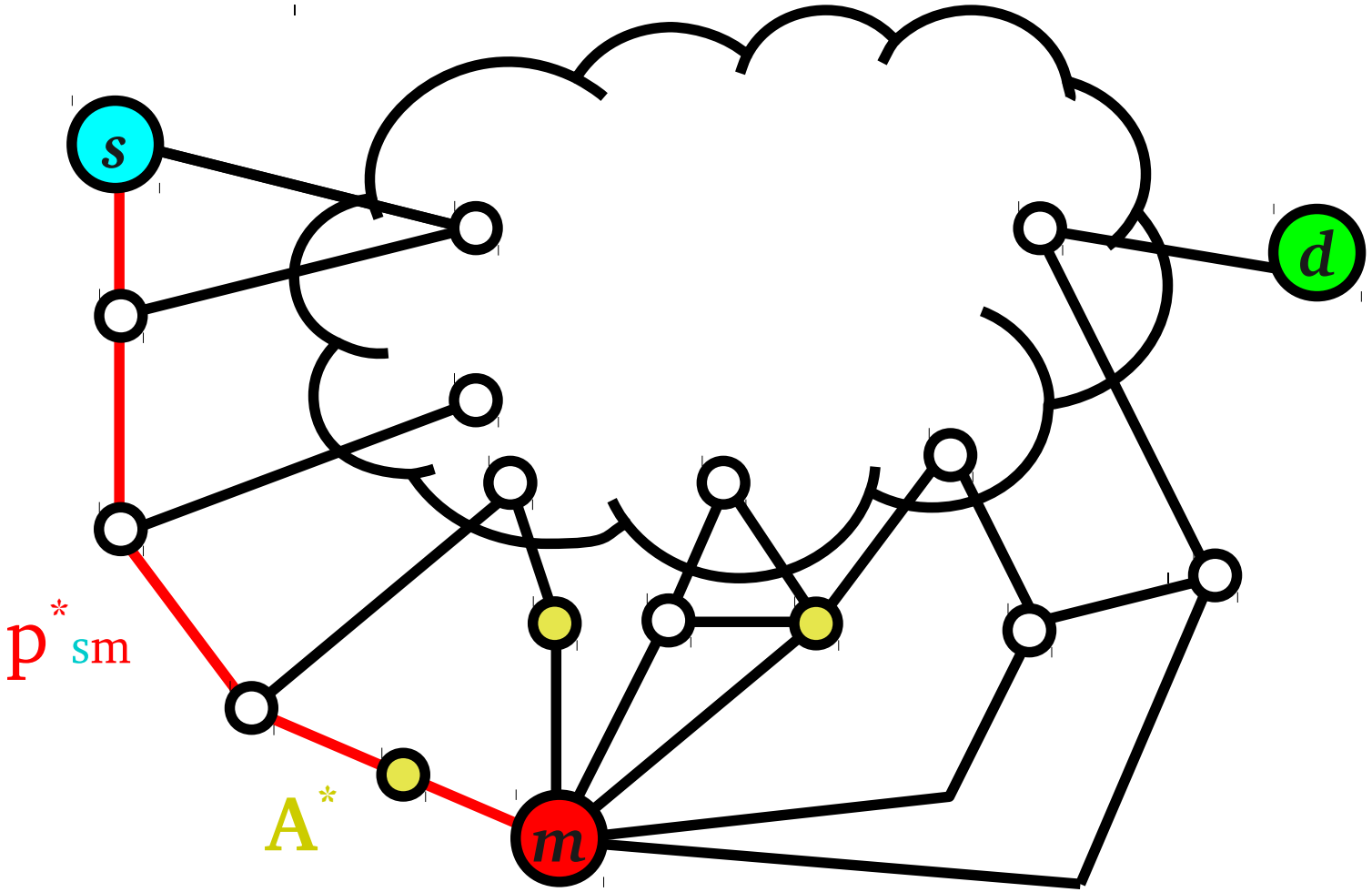
m attracts traffic announcing to A^*



A^* = set of neighbors to whom m announces the prefix

algorithm completeness (proof)

m attracts traffic through p^*_{sm}



Hijack Algorithm iteration on p^*_{sm}

Hijack Algorithm.

1: for each valley-free path p_{sm} from s to m

Hijack Algorithm iteration on p^*_{sm}: creation of A

Hijack Algorithm.

1: for each valley-free path p_{sm} from s to m
2: A = a set containing the neighbor of m in p_{sm}
3: for each neighbor n of m
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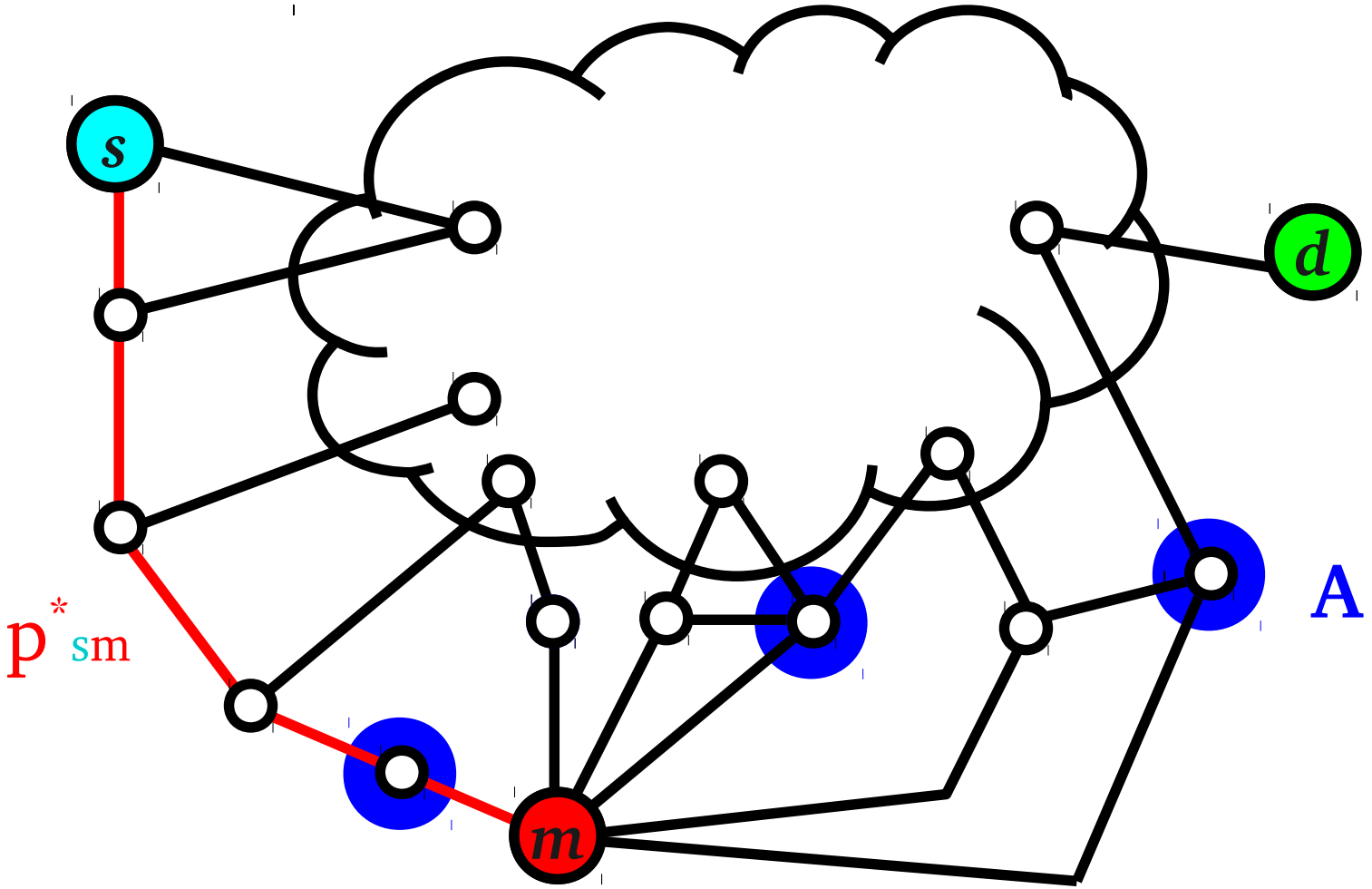
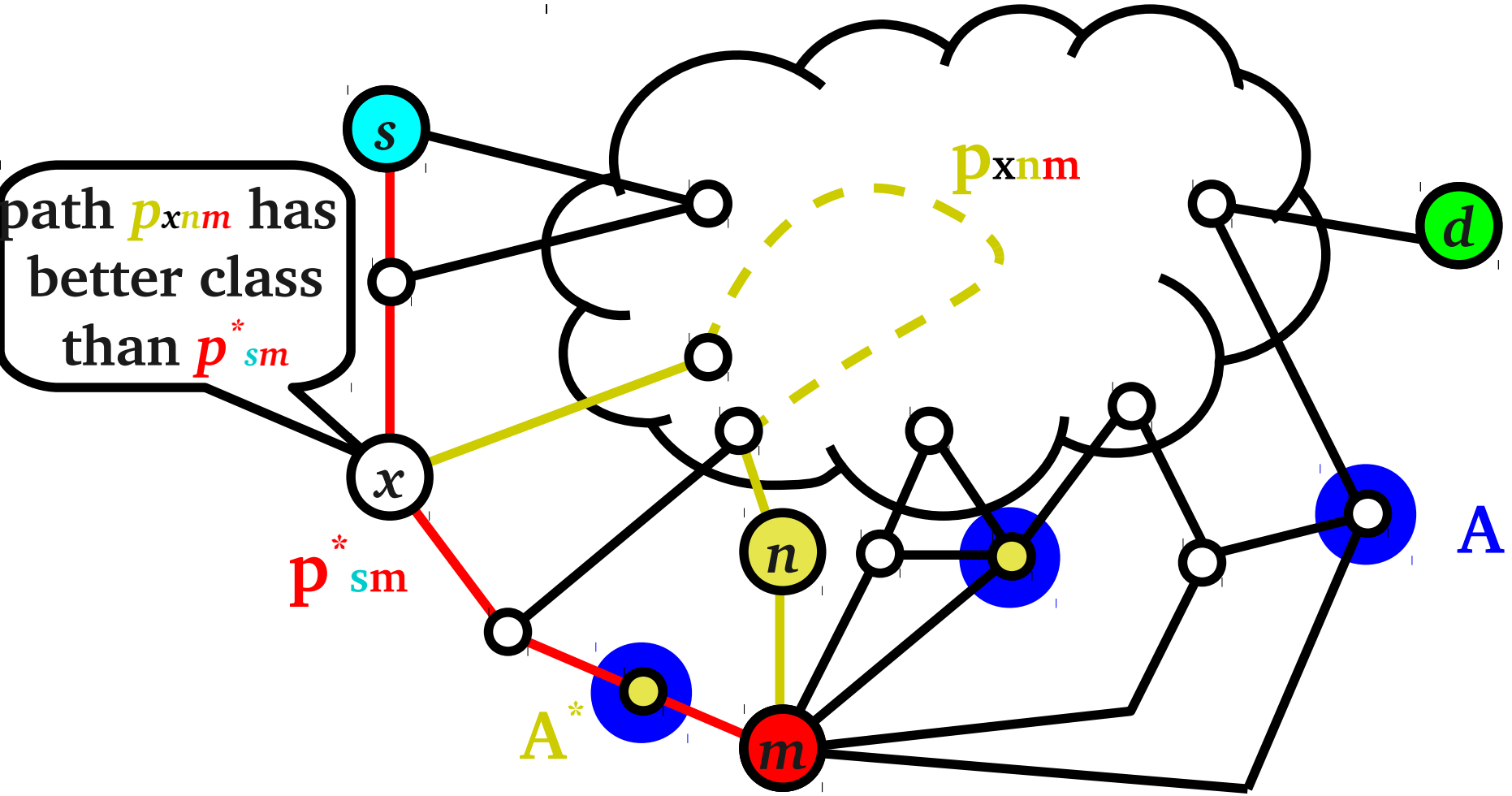
Hijack Algorithm iteration on p^*_{sm}

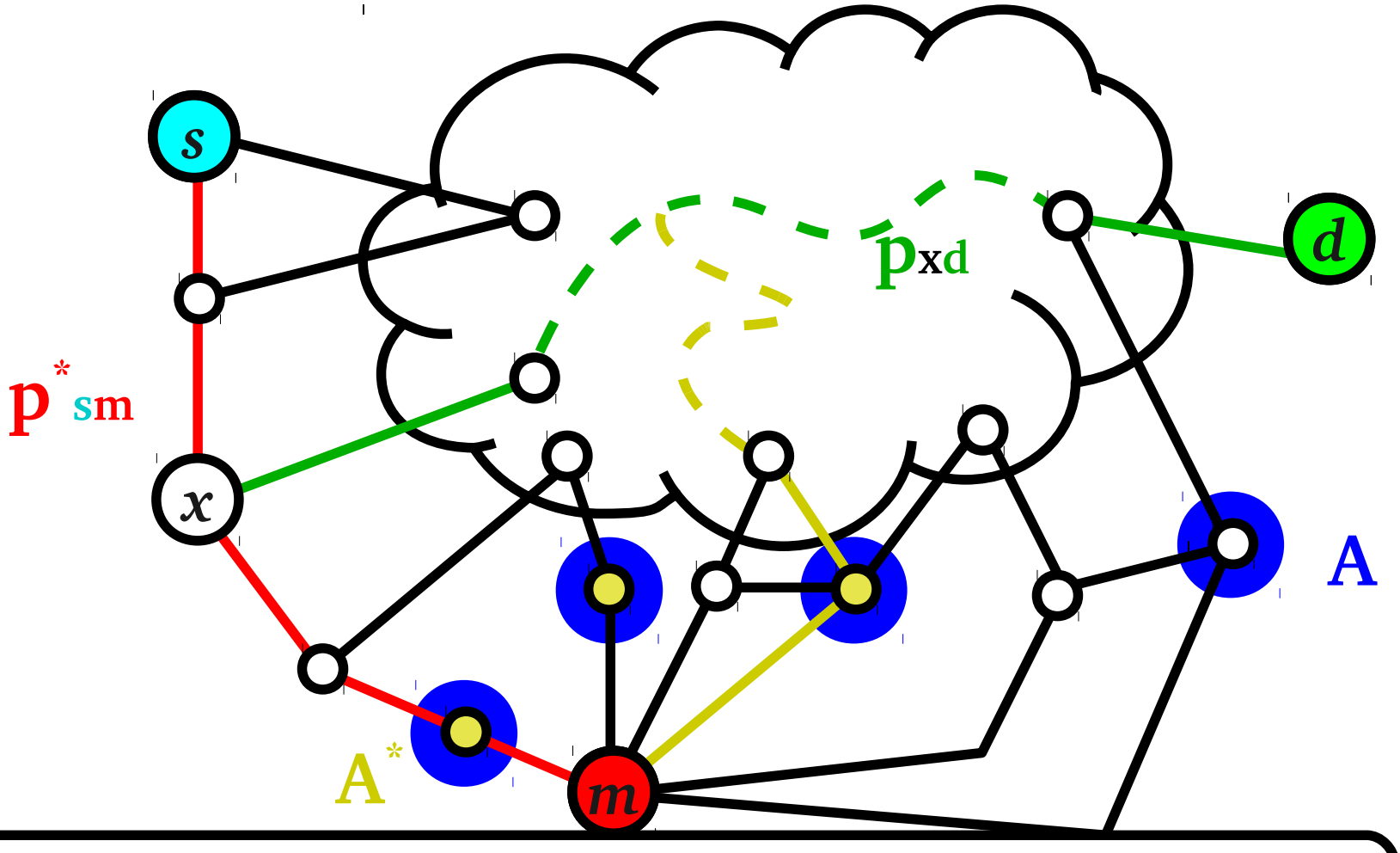


Hijack Algorithm iteration on p^*_{sm}:

A^* is contained in A (proof)



Hijack Algorithm iteration on p^*_{sm}: announcing to A → successful hijack

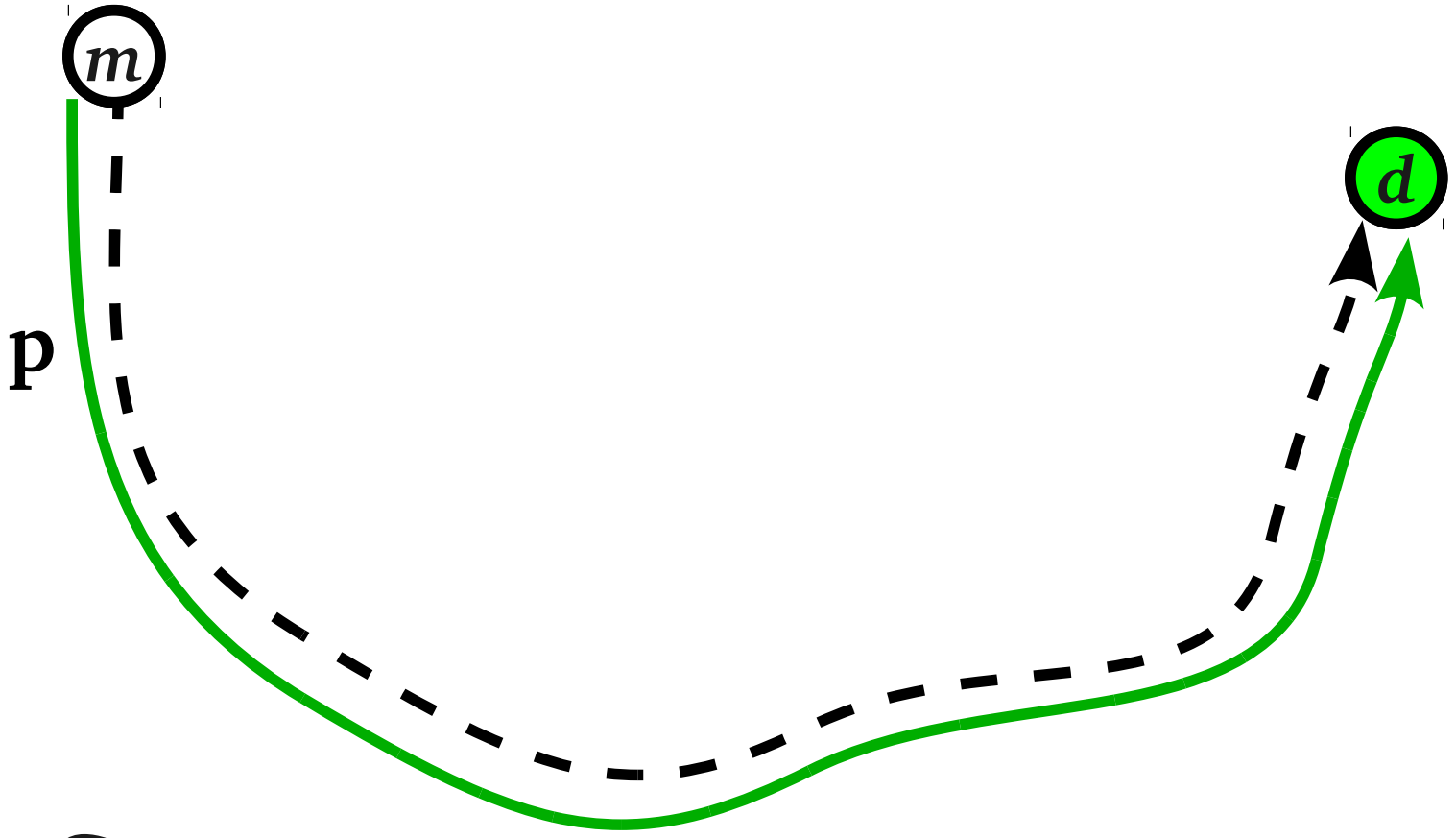


Lemma. p_{xd} is disrupted by better class

hijacking=interception in S-BGP

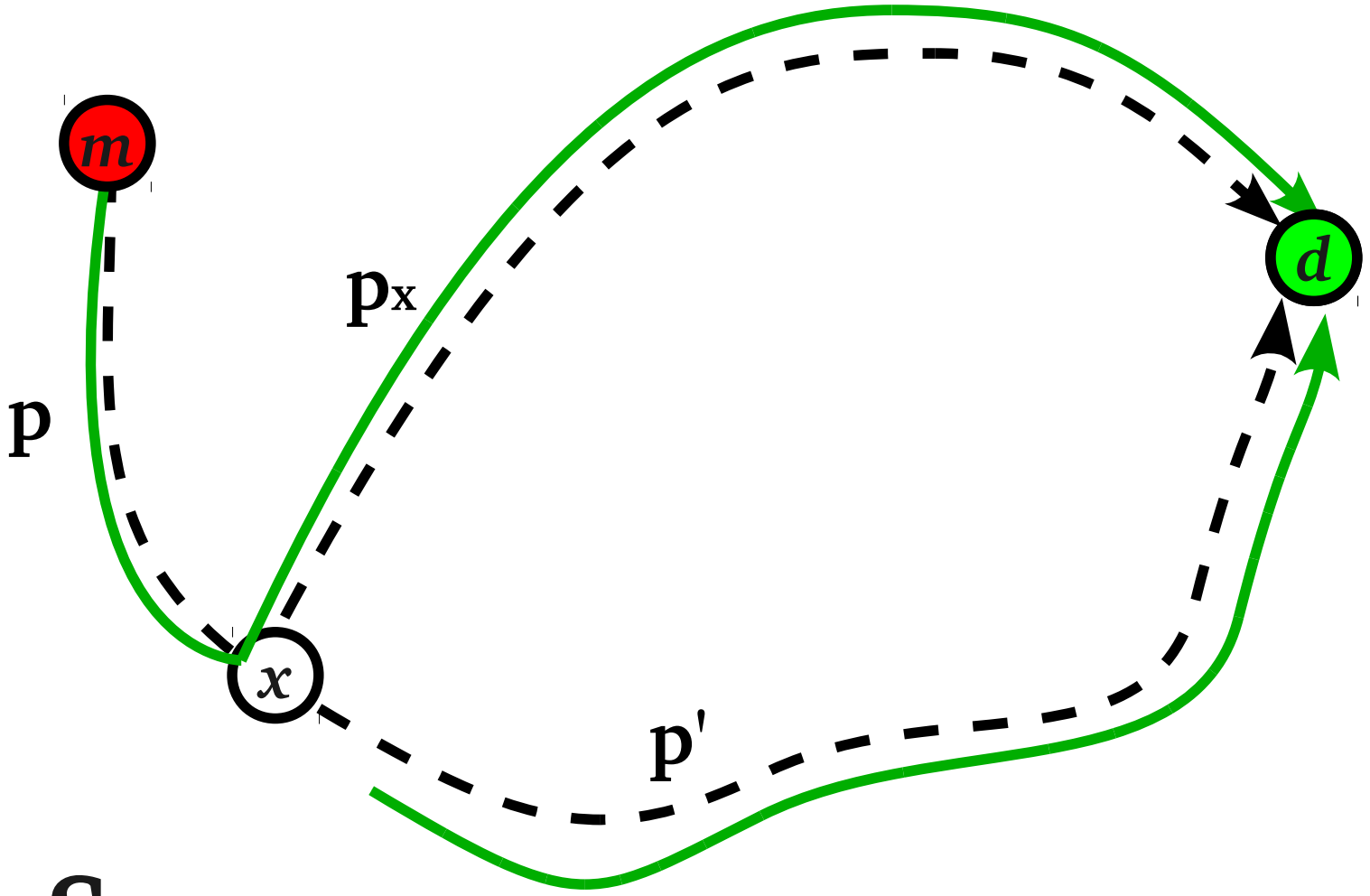
Theorem. If m announces the same path to any arbitrary set of its neighbors, then every successful hijacking attack is also a successful interception attack.

hijacking=interception in S-BGP



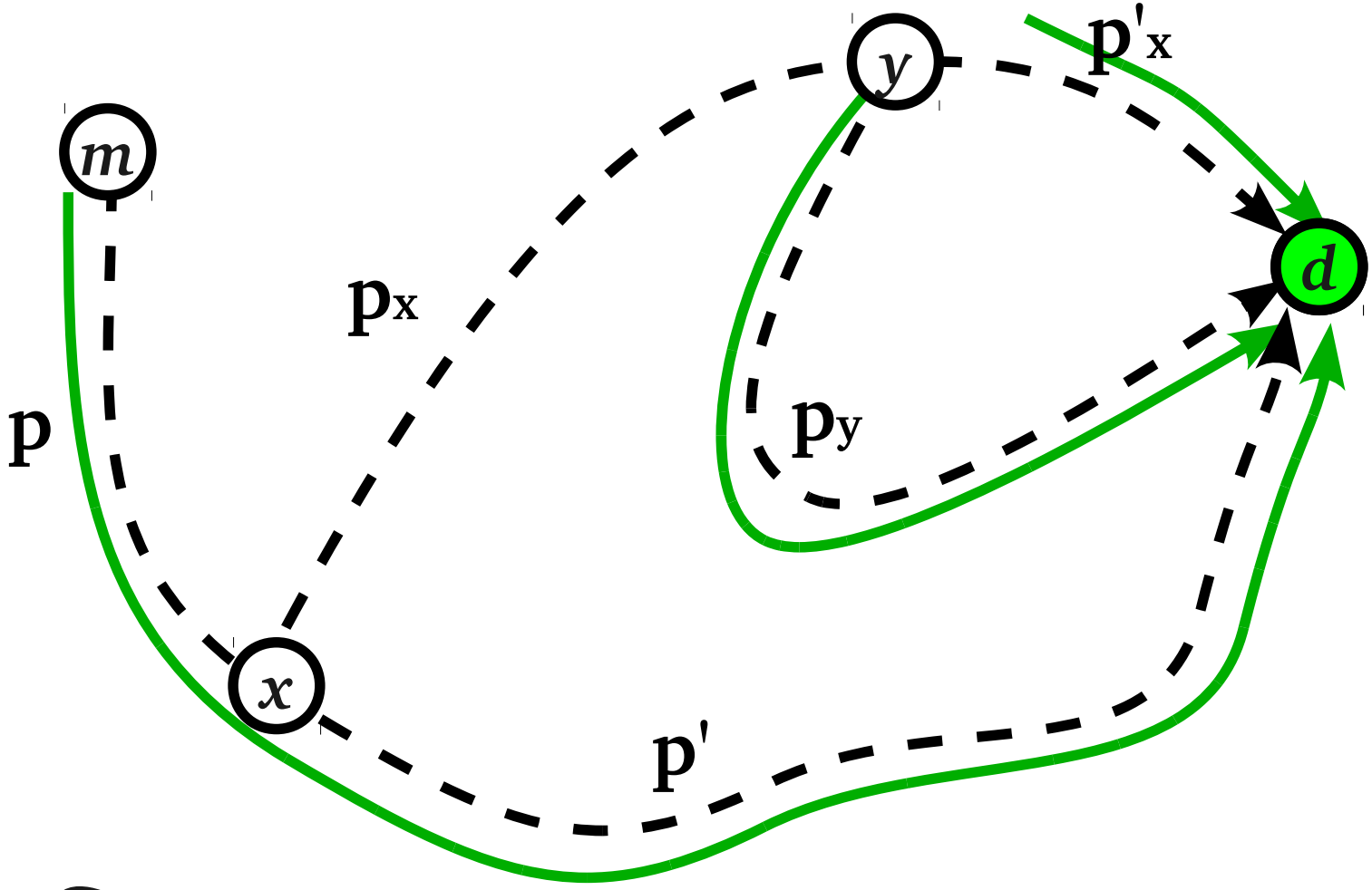
State S_1

hijacking=interception in S-BGP



State S_2

hijacking=interception in S-BGP



State S_1

hijacking != interception if manipulator announces different paths

Theorem. If m announces different paths to different vertices, then the hijacking may not be an interception.

routing oscillations

- we assumed that routing always **converges** to a **unique** and **stable** state

- BGP is known to be prone to routing oscillations

- if Gao-Rexford conditions holds, then routing always converges to a unique and stable state.
[GaoRexford, 2000]

- is it still true in the presence of a single manipulator?

no routing oscillations even in the presence of a manipulator

Theorem. Suppose that at a manipulator starts announcing steadily any set of arbitrary paths to its neighbors. Routing in G converges to a stable state.

this result has been also independently proved by Lychev, Goldberg, and Schapira (2012)

open problems

- We focused on a unique manipulator. How difficult is it to find a strategy involving **several malicious** ASes?

- In [SchapiraZhuRexford2010] it has been proposed to **disregard the AS-paths length** in the BGP decision process. How difficult is it to find an attack strategy in this different model?

thank you!