Power Adjusting and Bribery Racing: Novel Mining Attacks in the Bitcoin System

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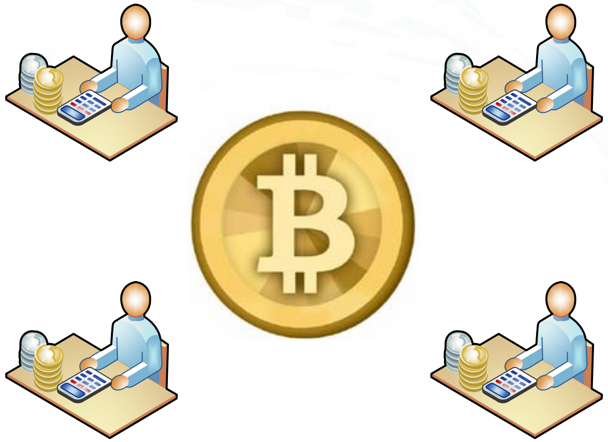
Outline

- Bitcoin Overview
- Mining Attacks
- Power Adjusting Withholding
- Bribery Selfish Mining
- Discussion
- Conclusion

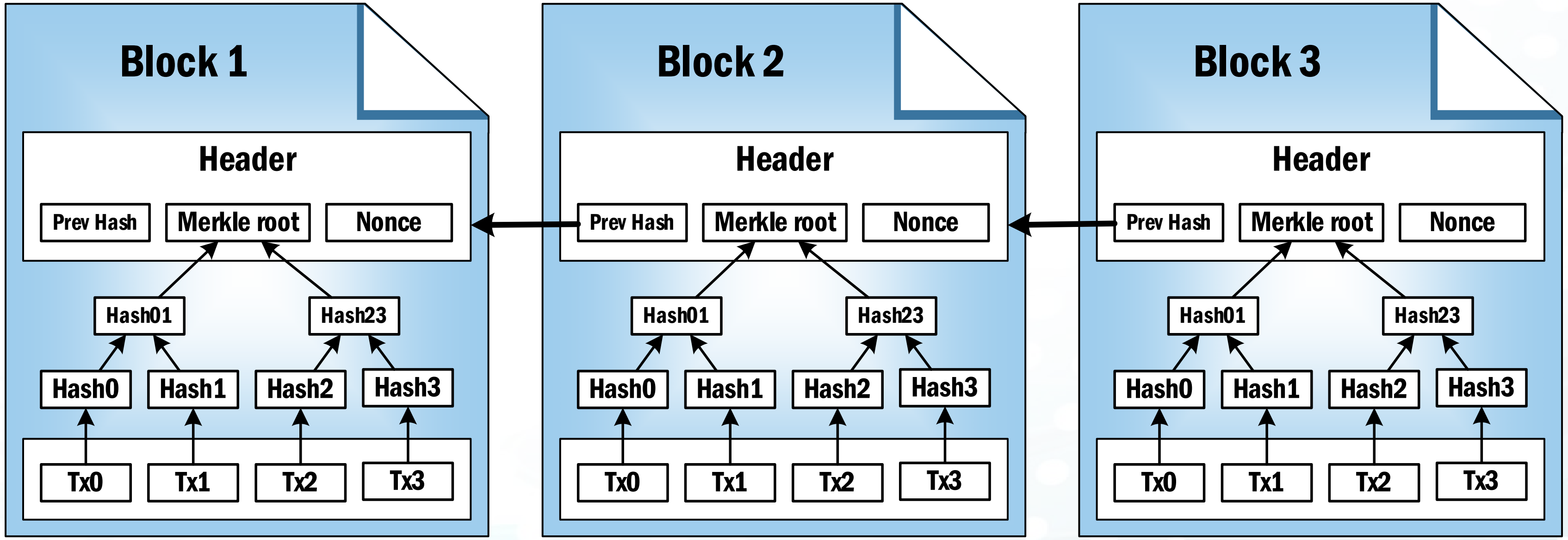
Bitcoin: Overview



- Blockchain based cryptocurrency
  - Decentralized ledger
- Price: more than 10000 USD in Aug, 2019.

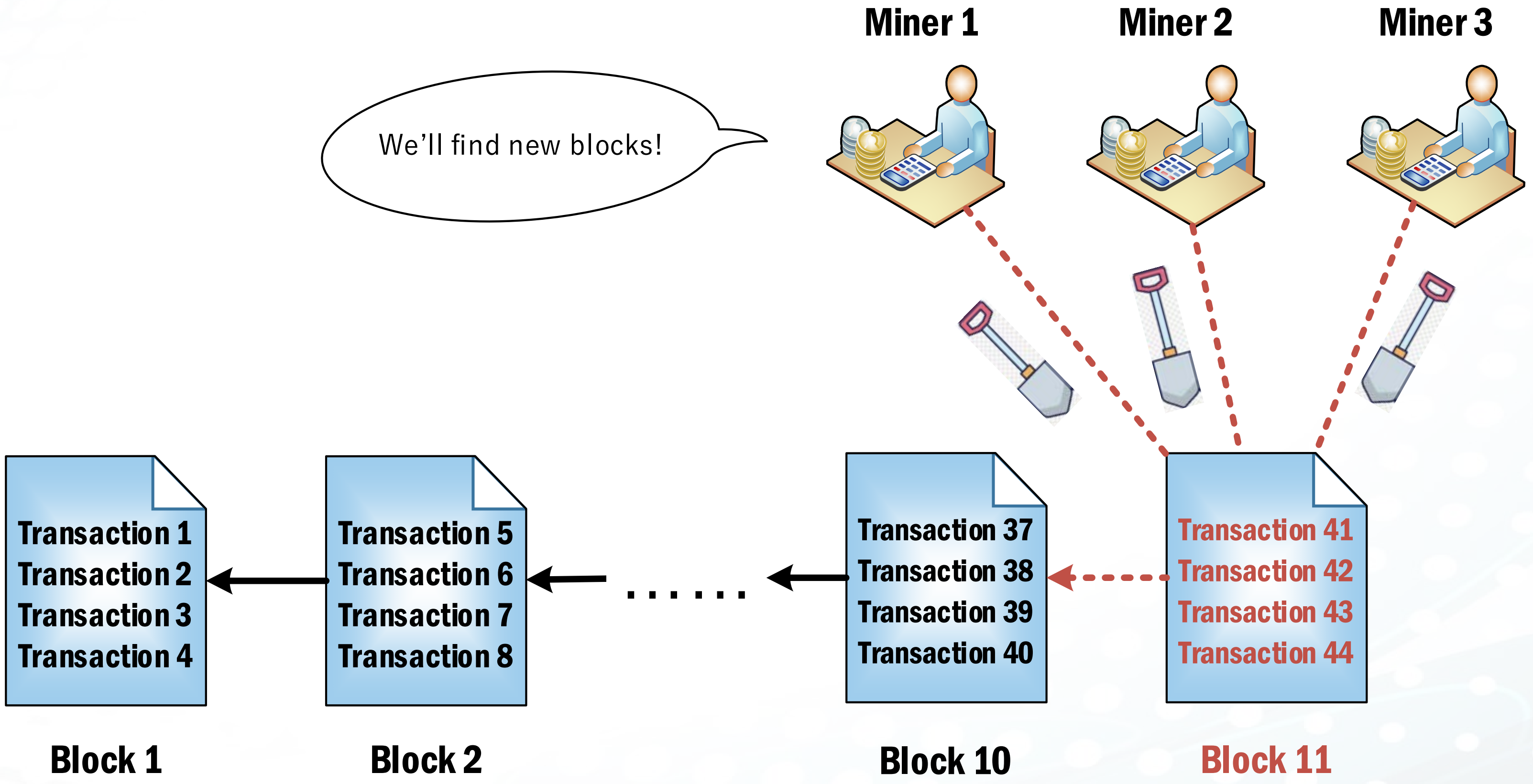
Bitcoin: Overview

- Participants: **miners.**
- New transaction records: recorded in **blocks.**
- Block: header and body
  - Header: previous block header hash, Merkle root, nonce, ...
  - Body: transaction records
- Ledger: **blockchain.**



Bitcoin: Mining Process

- **Mining process:** miners adding new blocks into the blockchain.

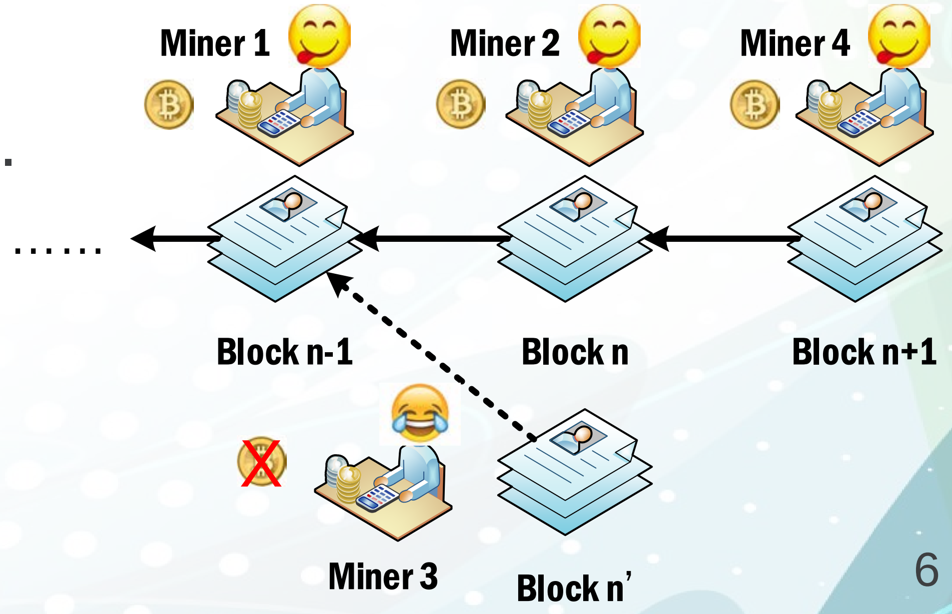


Bitcoin: Mining Process

- However, finding a new block is not easy.
  - Finding a proper **nonce** in the header that satisfies the difficulty constraint:

$$\boldsymbol{SHA256}\left(\boldsymbol{SHA256}(\boldsymbol{Block.Header})\right) < \boldsymbol{D}.$$

  - Need to enumerate all possible value.
- A proper nonce is called proof of work (**PoW**)
- The firstly discovered miner will be rewarded (12.5 BTC).

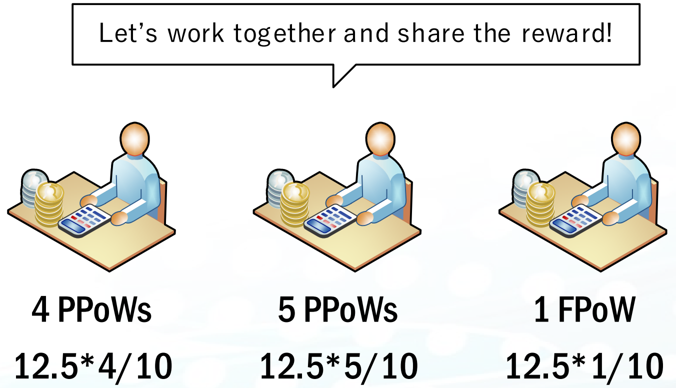


- Multiple miners find blocks simultaneously: **fork**.
  - A miner can choose which branch it works on.
  - The longest branch is selected as the main chain.
  - Only blocks on the main chain can be rewarded.

Bitcoin: Mining Pool

- To reduce the reward variance, miners can work together as **mining pools**.
  - Reward can be shared based on each miner's contribution.
  - Mining pool will set a less difficult constraint D' ($D' > D$).
  - A nonce that makes $D < Hash(header) < D'$ is called **PPoW** (partial proof of work).
  - A nonce that makes $Hash(header) < D < D'$ is called **FPoW** (full proof of work).
  - FPoWs and PPoWs are called shares. Number of shares is proportional to mining power.
  - A pool miner's reward is calculated by:

$$Miner's\ Reward = Pool's\ Reward * \frac{Number\ of\ miner's\ shares}{Number\ of\ total\ shares} = Pool's\ Reward * \frac{Miner's\ mining\ power}{Pool's\ mining\ power}$$



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Mining Attacks: Overview

- Attackers can increase their reward of mining when deviating from honest mining strategies.
  - Selfish mining [FC'14]
  - Block withholding [CSF'15, Oakland'15]
  - Fork after withholding [CCS'17]
  - Bribery attacks [FC'16]

[FC'14] Ittay Eyal and Emin Gun Sirer. 2014. Majority is not Enough: Bitcoin Mining is Vulnerable. In *Proc. of the International Conference on Financial Cryptography and Data Security (FC).*
[Oakland'15] Ittay Eyal. 2015. The Miner's Dilemma. In *Proc. of the IEEE Symposium onSecurity and Privacy (Oakland).*
[CSF'15] Loi Luu, Ratul Saha, Inian Parameshwaran, Prateek Saxena, and Aquinas Hobor. 2015. On Power Splitting Games in Distributed Computation: The Case of Bitcoin Pooled Mining. In *Proc. of the IEEE Computer Security Foundations Symposium (CSF).*
[CCS'17] Yujin Kwon, Dohyun Kim, Yunmok Son, Eugene Vasserman, and Yongdae Kim. 2017. Be Selfish and Avoid Dilemmas: Fork After Withholding (FAW) Attacks on Bitcoin. In *Proc. of the ACM Conference on Computer & Communications Security (CCS).*
[FC'16] Joseph Bonneau. 2016. Why Buy When You Can Rent?. In *Proc. of the International Conference on Financial Cryptography and Data Security (FC).*

Mining Attacks: Overview

- Attackers can increase mining when deviating from honest mining strategies.
  - Selfish mining [FC’14]
  - Block withholding [CSF’15, O

These attacks also work for other PoW based cryptocurrencies!

Cryptography and Data Security (FC).

[Oakland’15] Ittay Eyal. 2015. The Miner’s Dilemma. In *Proc. of the IEEE Symposium onSecurity and Privacy (Oakland).*

[CSF’15] Loi Luu, Ratul Saha, Inian Parameshwaran, Prateek Saxena, and Aquinas Hobor. 2015. On Power Splitting Games in Distributed Computation: The Case of Bitcoin Pooled Mining. In *Proc. of the IEEE Computer Security Foundations Symposium (CSF).*

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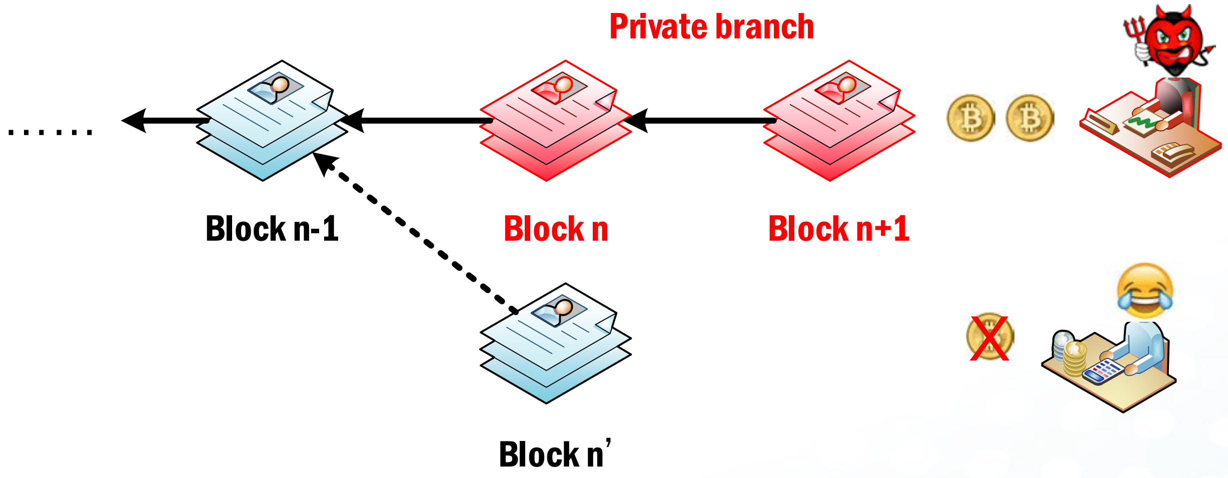
Mining Attacks: Selfish Mining

- An attacker will not publish the discovered block.
  - Continue mining on the discovered block as a **private branch**.
  - Publish the private chain when others discover a block (**cause a fork**).
  - Making others waste power when the private branch is selected as the main chain.



Mining Attacks: Selfish Mining

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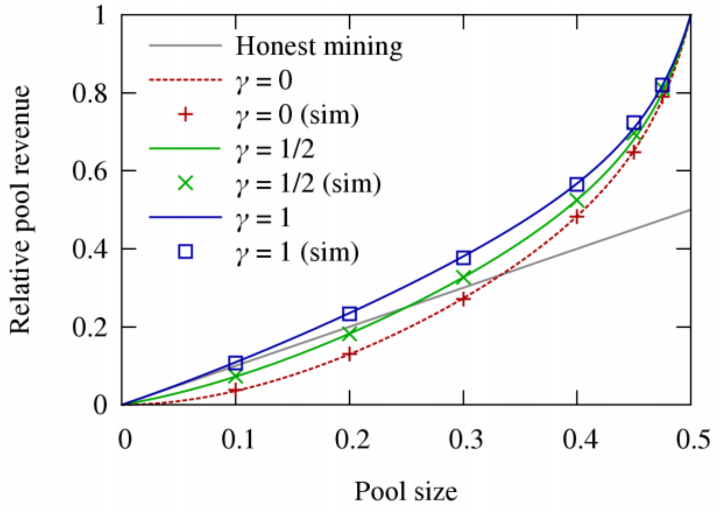
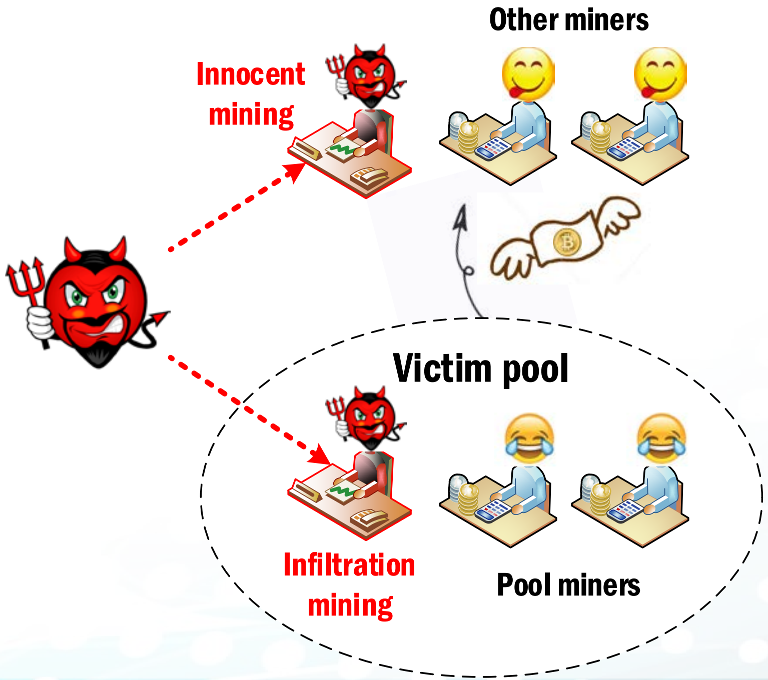
  - Continue mining on the discovered block as a **private branch**.
  - Publish the private chain when others discover a block (**cause a fork**).
  - Making others waste power when the private branch is selected as the main chain.

  - *Also may* ***lose*** *when the private branch is not selected as the main chain.*
  - *Need* ***1/3*** *mining power of the Bitcoin system to ensure a higher reward.*



Mining Attacks: Block Withholding (BWH)

- An attacker splits its power into innocent mining (mining solely) and infiltration mining (mining in pools).
  - Innocent mining: behaves exactly as honest mining.
  - Infiltration mining: only submits PPoWs (discards discovered FPoWs).
- Infiltration mining harms pools' reward, but makes other miners more profitable.



Mining Attacks: Block Withholding (BWH)

- BWH can be better than honest mining when splitting properly.
  - Regardless of mining power

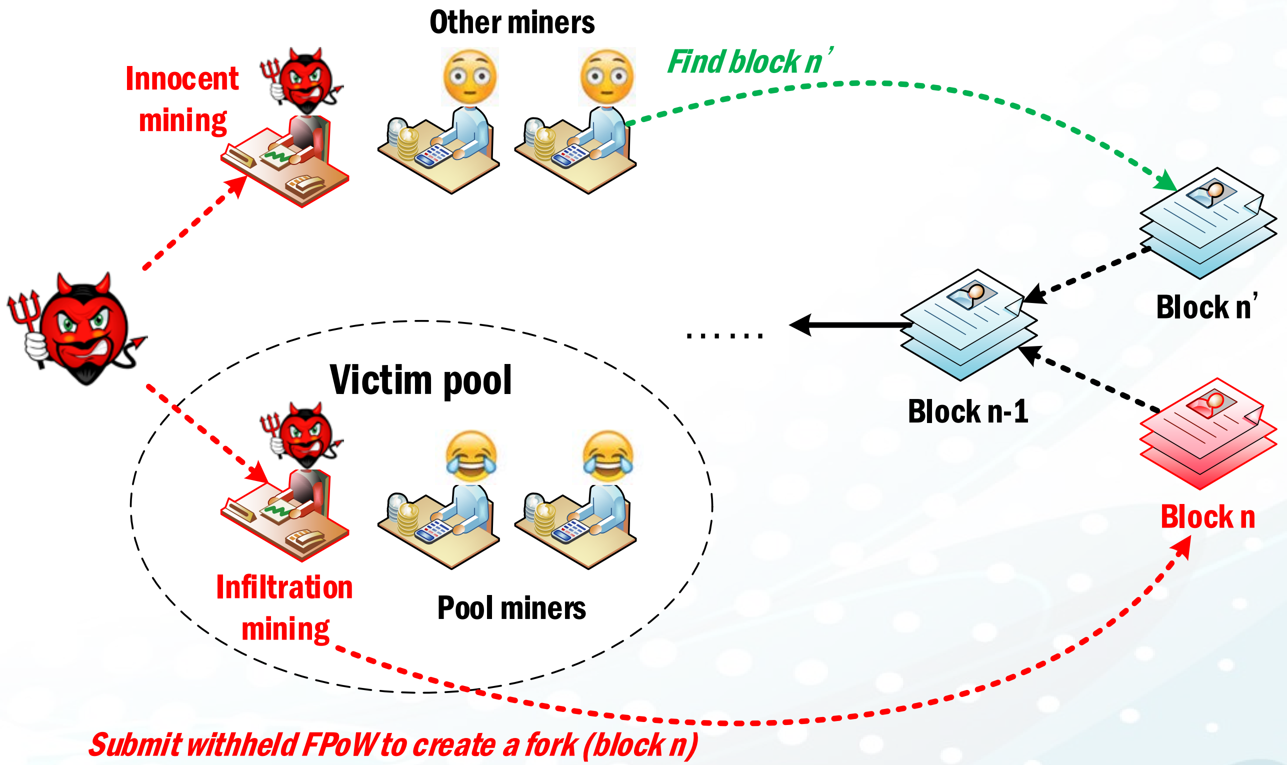
- Real-world BWH: Eligius pool lost 300 BTC in 2014.

- *It can be a "miner's dilemma" when two pools use BWH against each other.*
  - *Both pools will choose to attack under the Nash equilibrium.*
  - *Both pools always suffer from a loss due to BWH attacks (similar to the "prisoner's dilemma").*

Pool 2 \ Pool 1	no attack	attack
no attack	$(r_1 = 1, r_2 = 1)$	$(r_1 > 1, r_2 = \tilde{r}_2 < 1)$
attack	$(r_1 = \tilde{r}_1 < 1, r_2 > 1)$	$(\tilde{r}_1 < r_1 < 1, \tilde{r}_2 < r_2 < 1)$

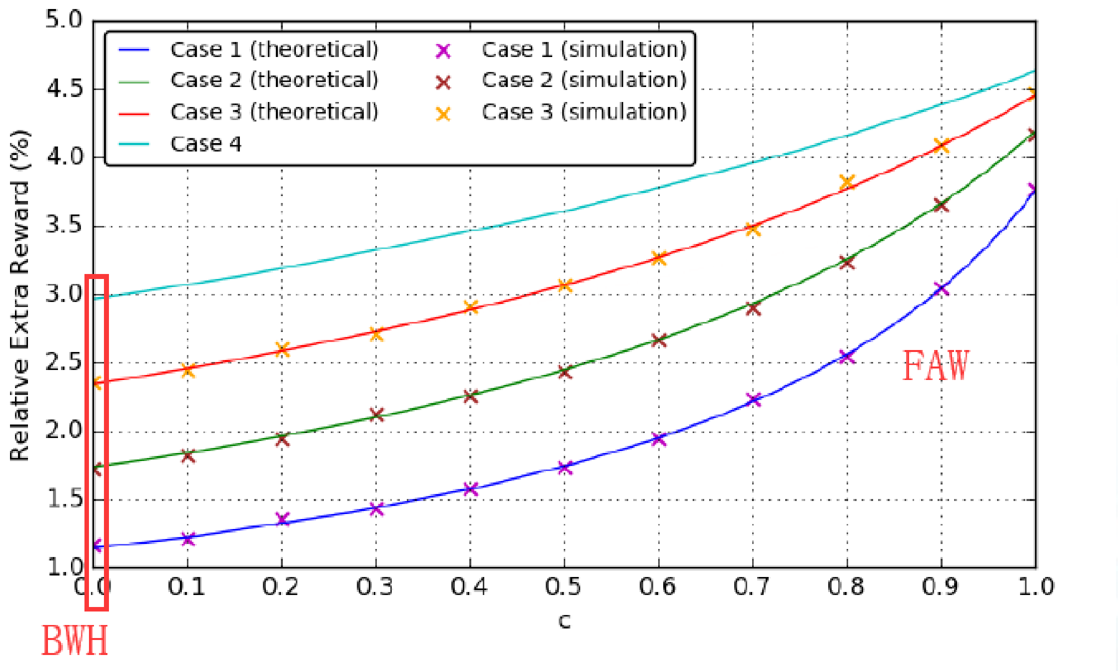
Mining Attacks: Fork After Withholding (FAW)

- FAW = BWH + Selfish Mining.
  - Splitting power into innocent mining and infiltration mining (as with BWH).
  - Infiltration mining withholds FPoWs, and *submits when others find blocks* (as with selfish mining).
    - Pool's reward: damaged by withholding FPoWs.
    - Other's reward: damaged by forks.



Mining Attacks: Fork After Withholding (FAW)

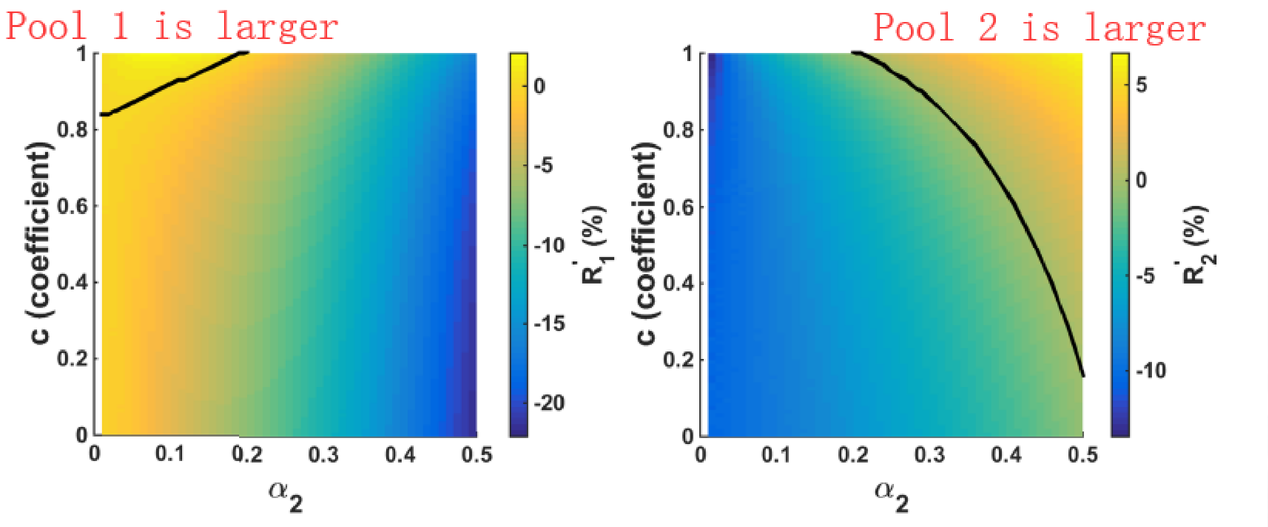
- Better than BWH.
  - The attacker can be rewarded from the fork (when attacker's branch becomes the main chain).
  - Lower bound is BWH (when attacker's branch is never selected).



Mining Attacks: Fork After Withholding (FAW)

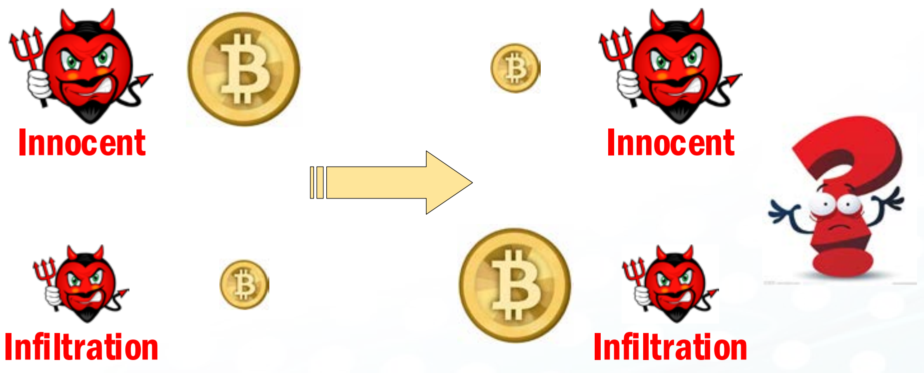
- Better than BWH.

- Break the dilemma: we may have a winner.
  - The smaller pool will always lose.
  - The larger pool may win.
  - Becoming a pool-size game.



Mining Attacks: Fork After Withholding (FAW)

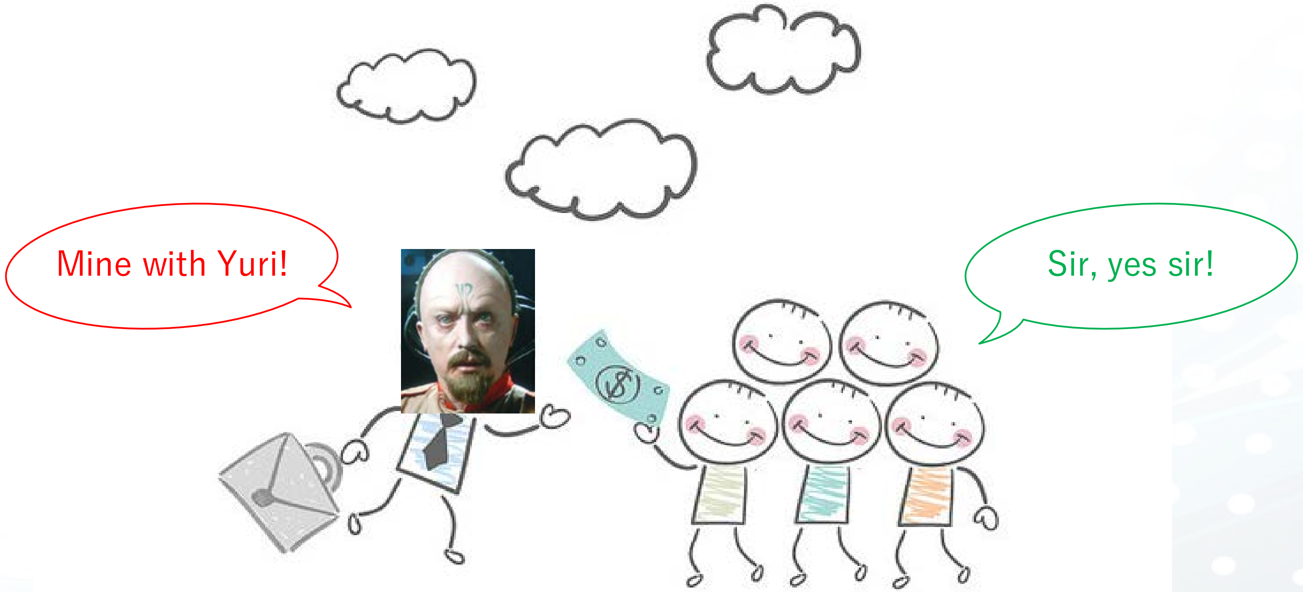
- Better than BWH.
- Break the dilemma: we may have a winner.
- *Fixed innocent-infiltration mining ratio*
  - *What if the value of one part of reward changes? E.g. shared reward becomes more “attractive”?*



Mining Attacks: Bribery Attacks

- When forks occur, attacker can bribe others to increase the chance of winning.
  - Sending "anyone can claim" transactions on attacker's branch
  - If bribes are considerable, others may be willing to work on attacker's branch.
    - Attacker may get more than 50% mining power in a short period (possible double-spending).

  - *Cost too much bribes to revert a long branch.*



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PAW: Observation

- In FAW, the value of the shared reward will change after infiltration mining finds an FPoW.

Case 1: *smaller* the pool, *higher* the chance to win in forks.

- When the pool size is small, I can share more profit if I allocate more power into it.
- Even when forks occur, I have a high chance to get a share.

The share is more attractive!

Case 2: *larger* the pool, *less* the chance to win in forks.

- Even when I allocate more power, I still get little shared reward.
- When forks occur, I only get very few shares

The share is less attractive!

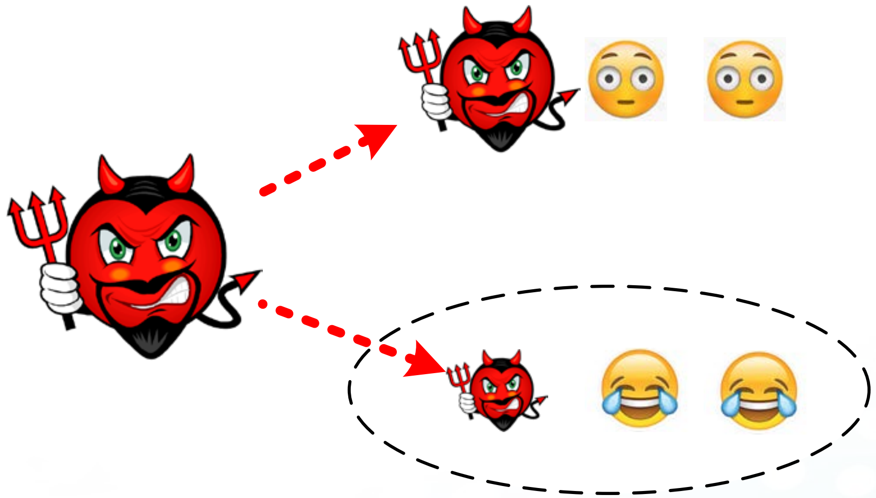
PAW: Observation

- In FAW, the shared reward's value will change after infiltration mining finding an FPoW.

Why not adjust my power splitting after finding an FPoW!

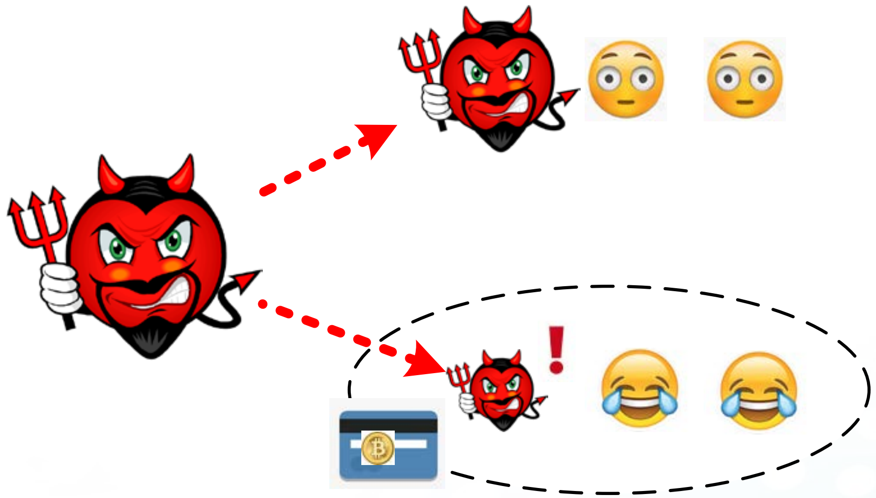
PAW: Power Adjusting Withholding

- PAW = <u>P</u>ower <u>A</u>djusting + FA<u>W</u>
  - Splitting power into innocent mining and infiltration mining (as with FAW).



PAW: Power Adjusting Withholding

- PAW = **P**ower **A**djusting + FA**W**
  - Splitting power into innocent mining and infiltration mining (as with FAW).
  - When infiltration mining finds an FPoW, *adjust power splitting strategy*.



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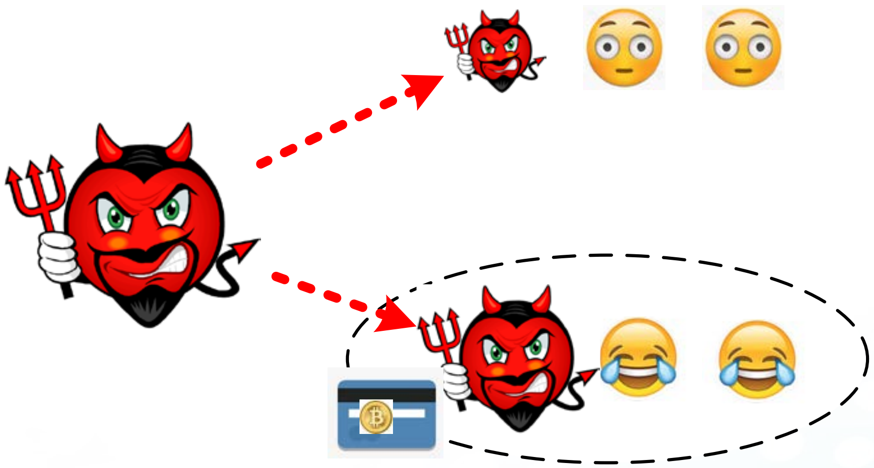

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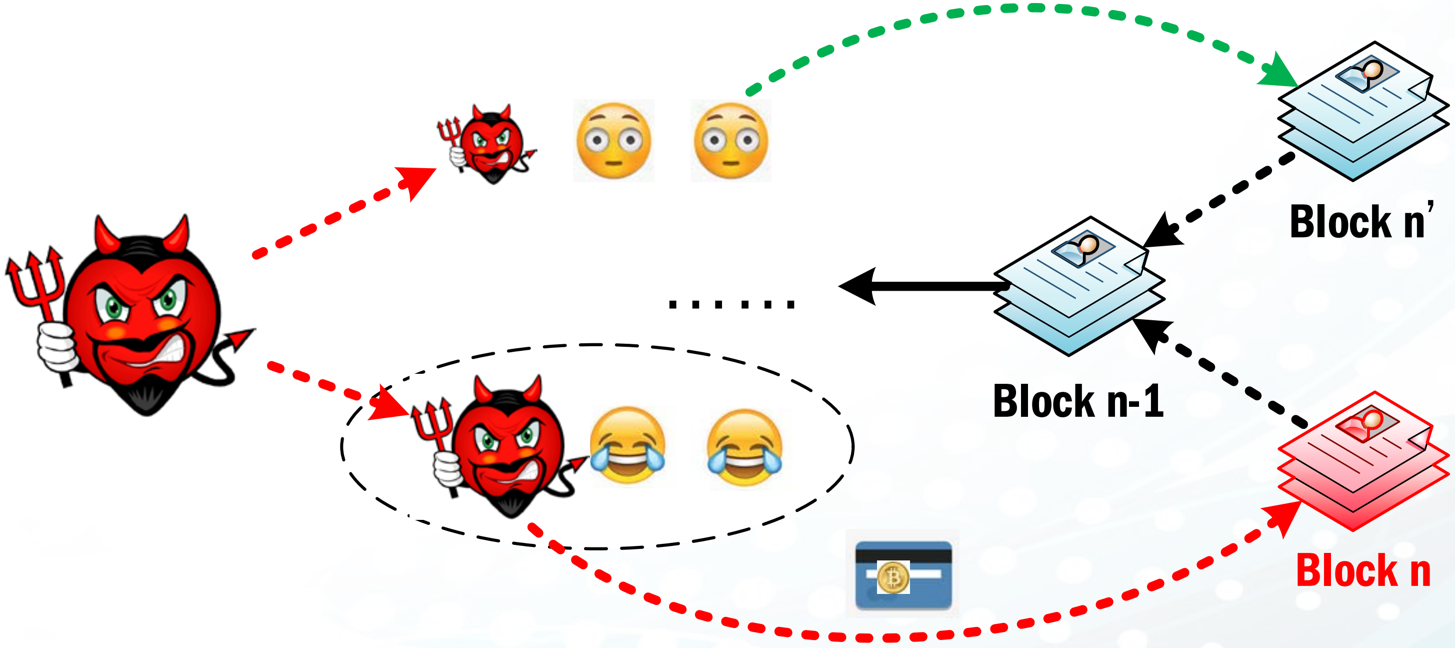

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  - Splitting power into innocent mining and infiltration mining (as with FAW).
  - When infiltration mining finds an FPoW, *adjust power splitting strategy*. NEW!
  - Infiltration mining withholds FPoWs, and submits when others find blocks (as with FAW).

- How to adjust power?
  - Based on the optimizing function.

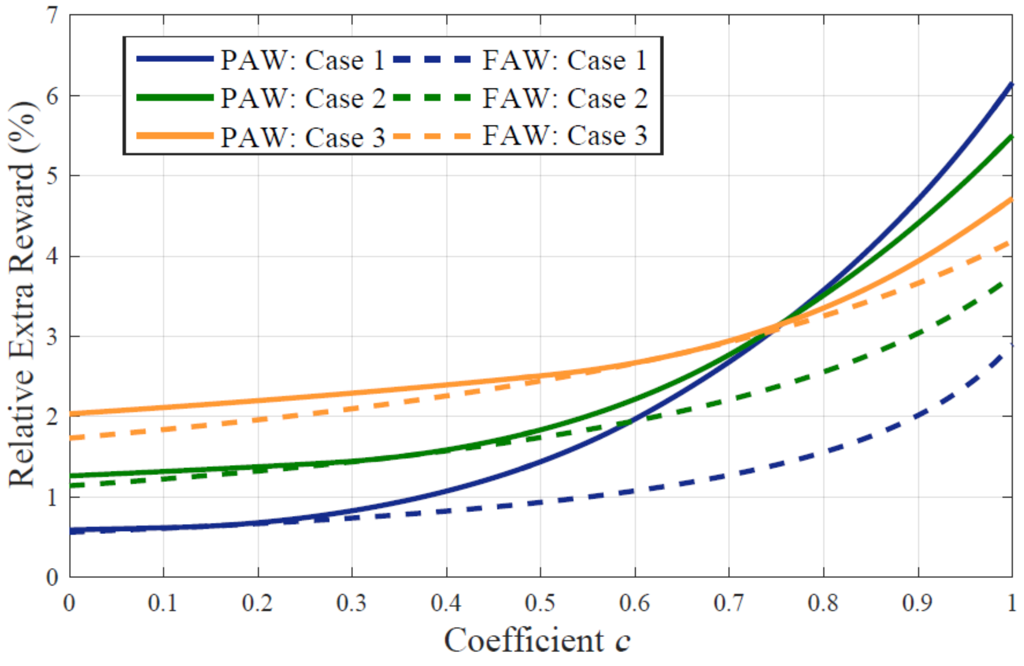
$$R_a^P(\tau_1, \tau_2) = (1-\tau_1)\alpha + \beta \cdot \frac{\tau_1\alpha}{\beta + \tau_1\alpha} + \tau_1\alpha \cdot \left(\frac{(1-\tau_2)\alpha}{1-\tau_2\alpha} + \left(c \cdot \frac{1-\alpha-\beta}{1-\tau_2\alpha} + \frac{\beta}{1-\tau_2\alpha}\right) \cdot \frac{\bar{\tau}\alpha}{\beta + \bar{\tau}\alpha}\right),$$

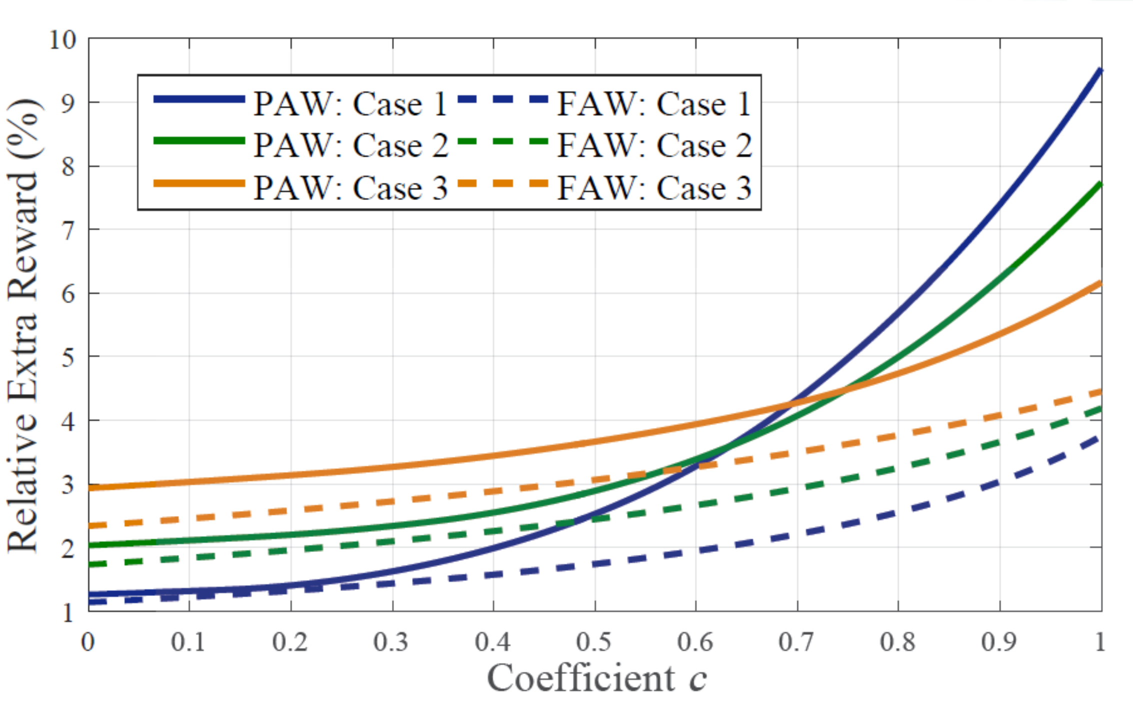
$$\arg\max_{\tau_1, \tau_2} R_a^P(\tau_1, \tau_2), \quad 0 \leqslant \tau_1 \leqslant 1, \quad 0 \leqslant \tau_2 \leqslant 1.$$

  - Allocating more power to infiltration mining when the share is more attractive; less power when less attractive.

PAW: Higher Reward

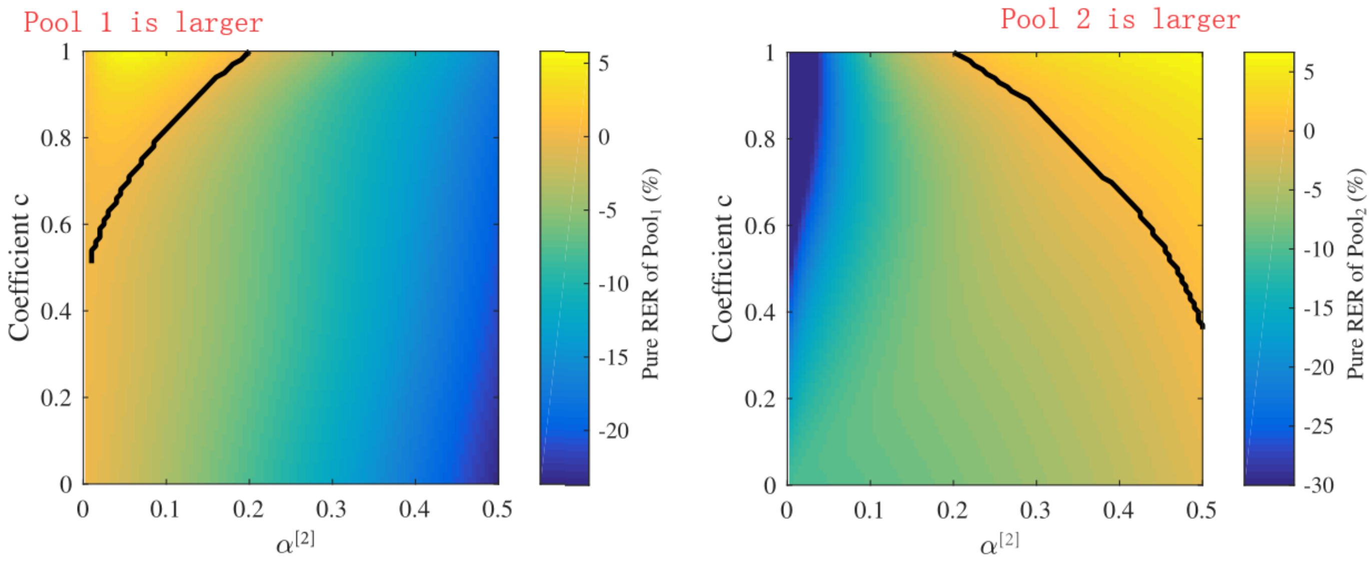
- Better than FAW.
  - We can ensure PAW = FAW with an additional constraint: $\tau_1 = \tau_2$ (not adjusting).
  - Without the additional constraint, PAW will get a better result (higher reward) than FAW.





PAW: Avoiding Dilemma

- Avoiding the “miner’s dilemma”.
  - Pool-size game: smaller pool will lose, larger pool may win.



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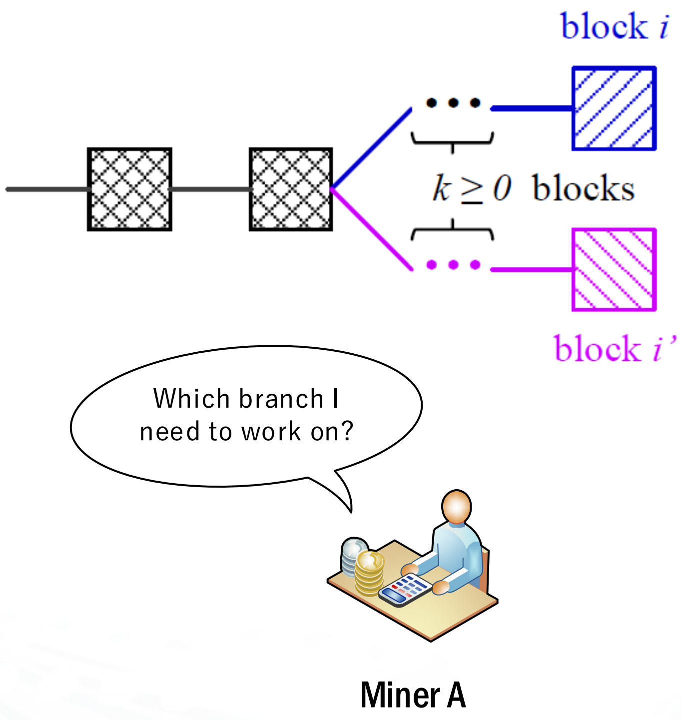
BSM: 0-Lead Racing

- 0-lead racing: two branches of the same length racing in the system.
  - Other miners have no difference in working on which branch
  - Typical scenario: selfish mining



Case 1, ***A*** finds a block: he will get a reward and continue mining on the current branch.

Case 2, ***A*** does not find: he will switch to the main branch (if necessary) and continue mining.

No difference between blue and pink branches!

BSM: Observation

- When 0-lead racing occur, attacker can “lure” others to work on his branch.
  - Increase the chance of winning in forks with little cost.

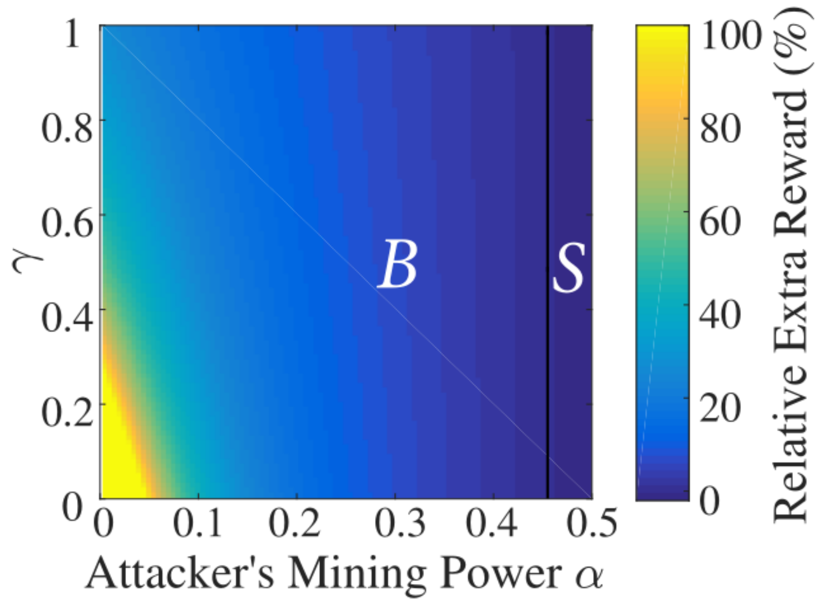
Why not bribe others (with little cost) to work on my branch!

BSM: Bribery Selfish Mining

- BSM = **B**ribery attacks + **S**elfish **M**ining
  - Publish the private branch when public branch catches up to cause 0-lead racing in selfish mining.
  - Including bribery transactions when mining the new private block.
  - When mining the second private block, transferring the money back and including new bribery transactions.

BSM: Higher Reward

- More venal miners = better chance of wining in forks
  - A critical parameter in selfish mining: the ratio of venal miners
  - Can be more profitable than selfish mining with a proper amount of bribes.

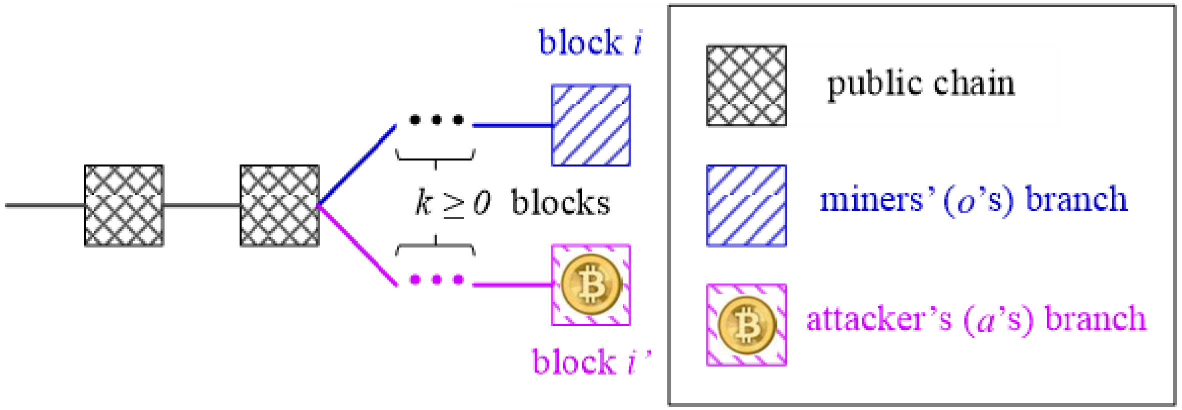


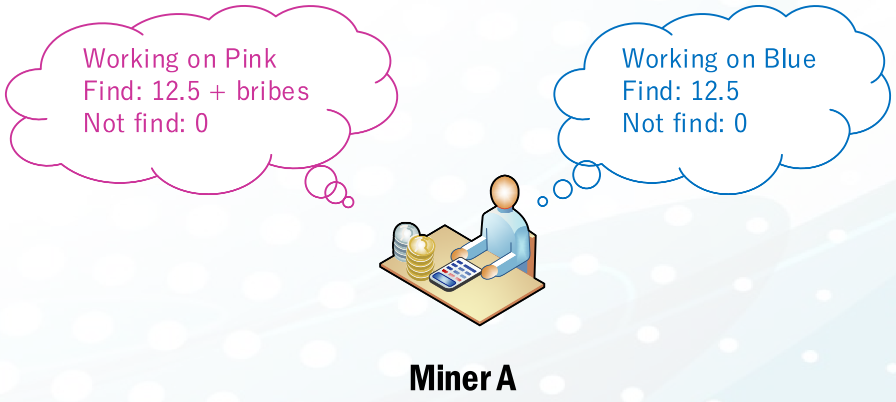
Attacker’s dominant strategy (BSM VS selfish mining).

bribes = 0.02; B = BSM; S = Selfish mining

BSM: Higher Reward

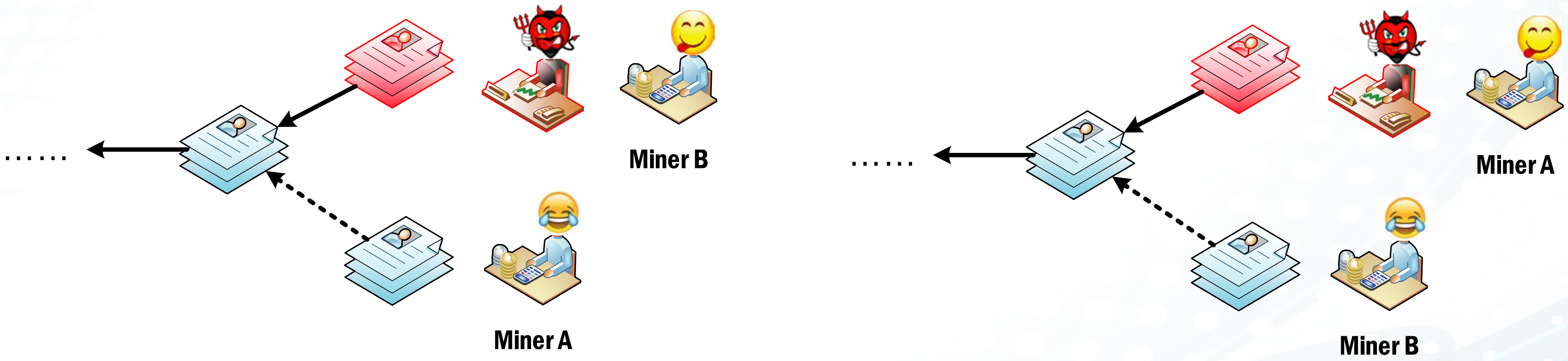
- More venal miners = better chance of wining in forks
  - A critical parameter in selfish mining: the ratio of venal miners
  - Can be more profitable than selfish mining with a proper amount of bribes.
- How much to pay for bribes?
  - **Almost nothing!** As long as bribes > 0.
  - Profit-driven miners: something is better than nothing





BSM: The Venal Miner's Dilemma

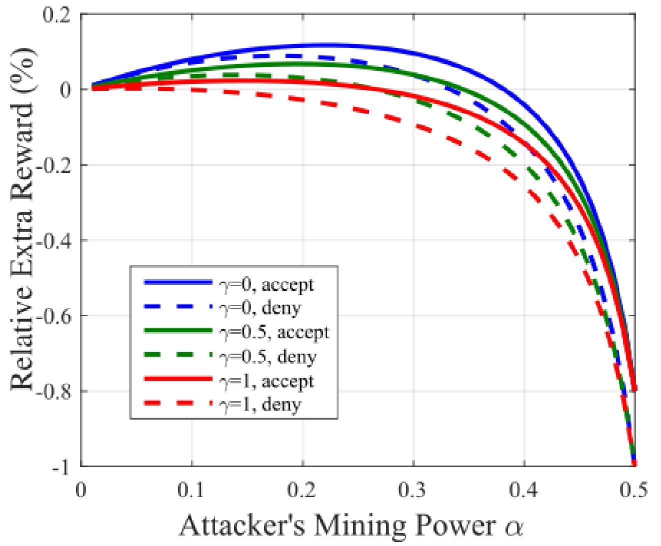
- What if the attacker races with venal miner?
  - For miner A and B, their dominant strategy is mining on attacker's branch.
  - A and B are harming each other's profit, while making the attacker more profitable!



BSM: The Venal Miner's Dilemma

- What if the attacker races with venal miner?
  - For miner A and B, their dominant strategy is mining on the attacker's branch.
  - A and B are harming each other's profit, while making the attacker more profitable!

  - When more venal miners are involved, there will be a "venal miner's dilemma".
    - All venal miners choose to accept the bribes (mine on the attacker's branch), but will suffer from a lost comparing with none acceptance.



Target_2 \ Target_1	Accept at $0'_o$	Deny at $0'_o$
Accept at $0'_o$	(**-2.58%**, **-0.62%**)	(-6.44%, **1.63%**)
Deny at $0'_o$	(**3.85%**, -1.85%)	(0.45%, 0.45%)

BSM: Venal Miner’s Dilemma VS Miner’s Dilemma

- Differences between the “miner’s dilemma”:

	Venal Miner’s Dilemma	Miner’s Dilemma
Participants	1 attacker, 2 venal miners	2 attackers, and other miners
Beneficiary	Attacker	Other miners
Victim	Venal miners	Attackers
Good property for the attack?	Yes	No

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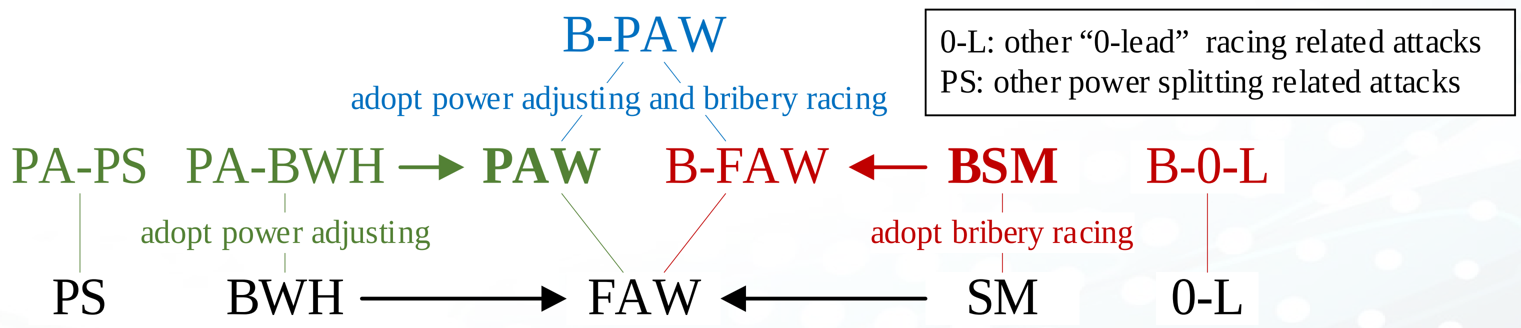
Discussion: Attack Strategy Space

- PAW: power splitting related.
  - The idea of power adjusting can be used to other power splitting related attacks, after some part of reward value changes.
    - E.g., power adjusting + BWH = PA-BWH.
- BSM: 0-lead racing related.
  - The idea of bribery can be applied to other 0-lead racing related attacks.
    - E.g., Bribery + FAW = B-FAW; Bribery + PAW = B-PAW.



Discussion: Countermeasure

- PAW detection.
  - Power adjusting is hard to be detected.
    - Not always happen: only after infiltration mining finds an FPoW.
    - Non-frequent power adjusting is legal and acceptable for honest miners.
  - PAW can be detected via BWH/FAW detection.
    - BWH detection: statistic (PPoW/FPoW ratio).
    - FAW detection: stale FPoWs.
      - Timestamp based detection: synchronize miner's time; verify timestamp field.

- PAW attacker can use Sybil nodes when detected to get more profit.

Open problem to prevent PAW

Discussion: Countermeasure

- Bribery countermeasures.
  - Restrict the use of “anyone can claim” transactions.
    - *Sacrifice the flexibility and programmability.*
  - Miners should preferentially choose the branch containing the transactions which they previously received.
    - *Unrealistic to assume all miners adopt this approach.*
  - Pool managers should expel pool miners who submit FPoWs containing bribes.
    - Avoiding bribery racing in FAW/PAW.
    - Pool miners should leave pools when pools accept FPoWs containing bribes.

- Bribery related attacks are hard to be avoided.
  - Greedy.
  - Out-of-band transactions.

No silver bullet

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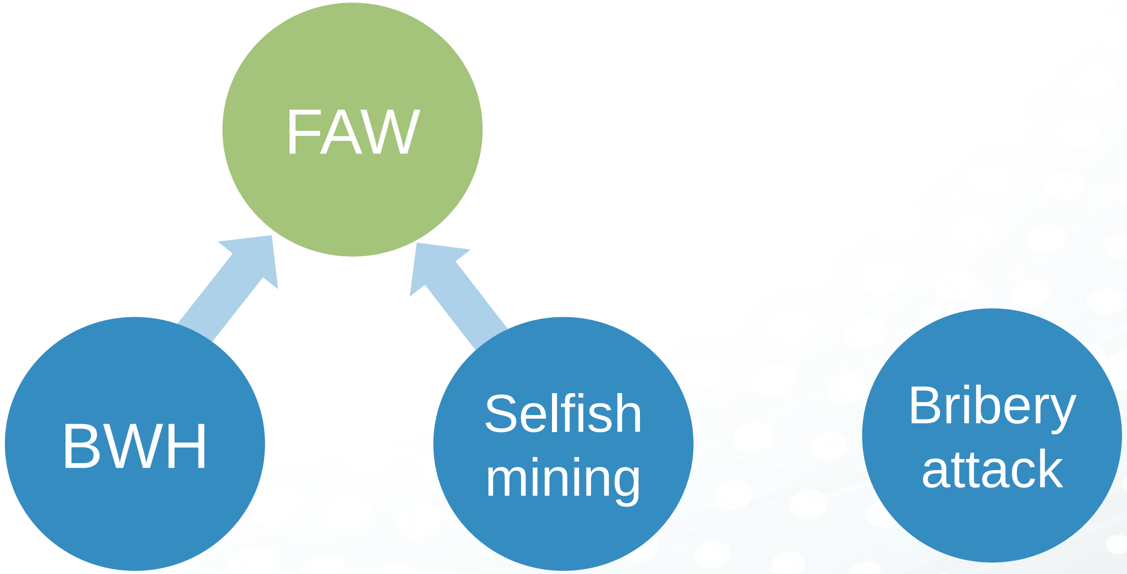

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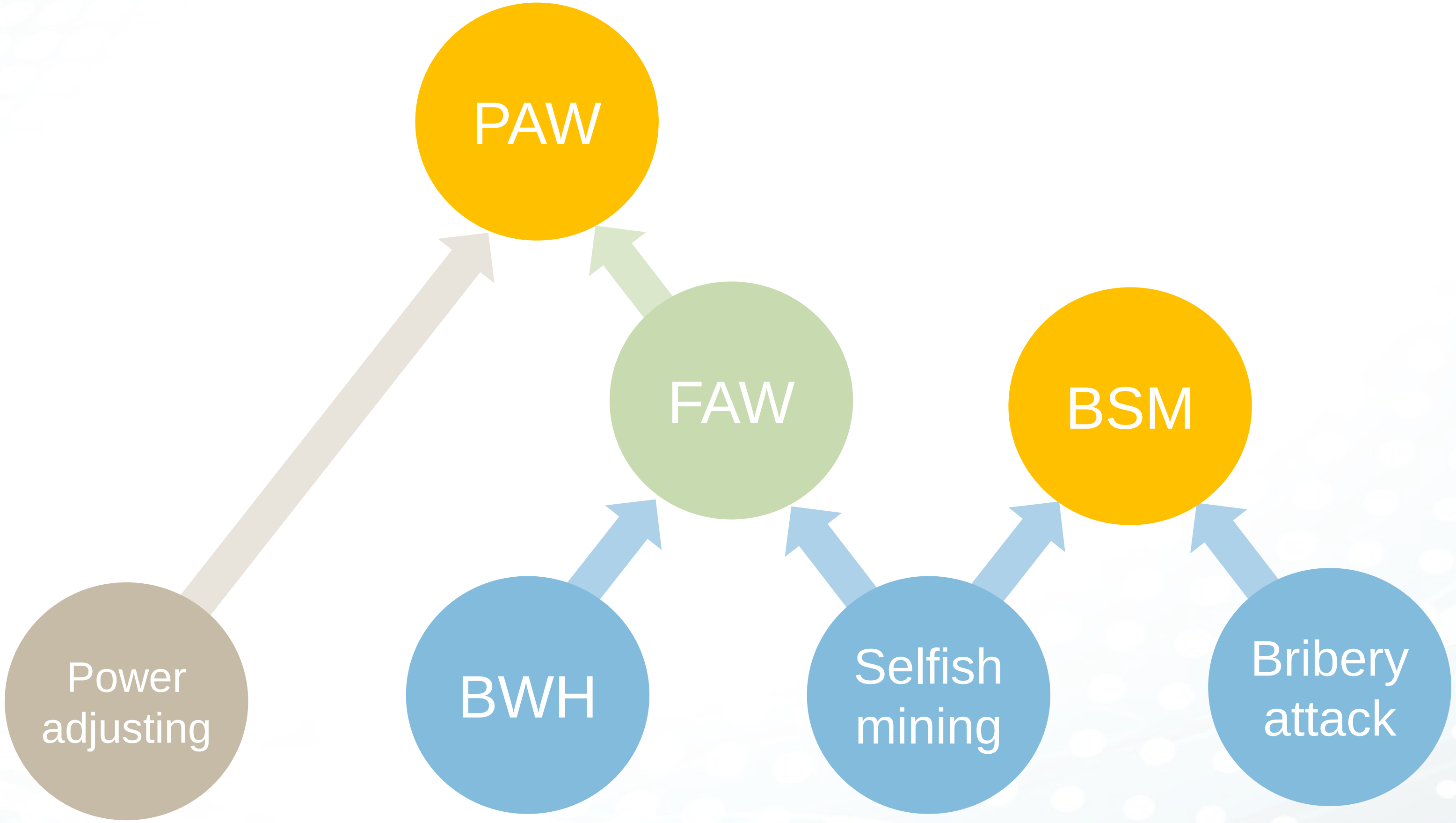
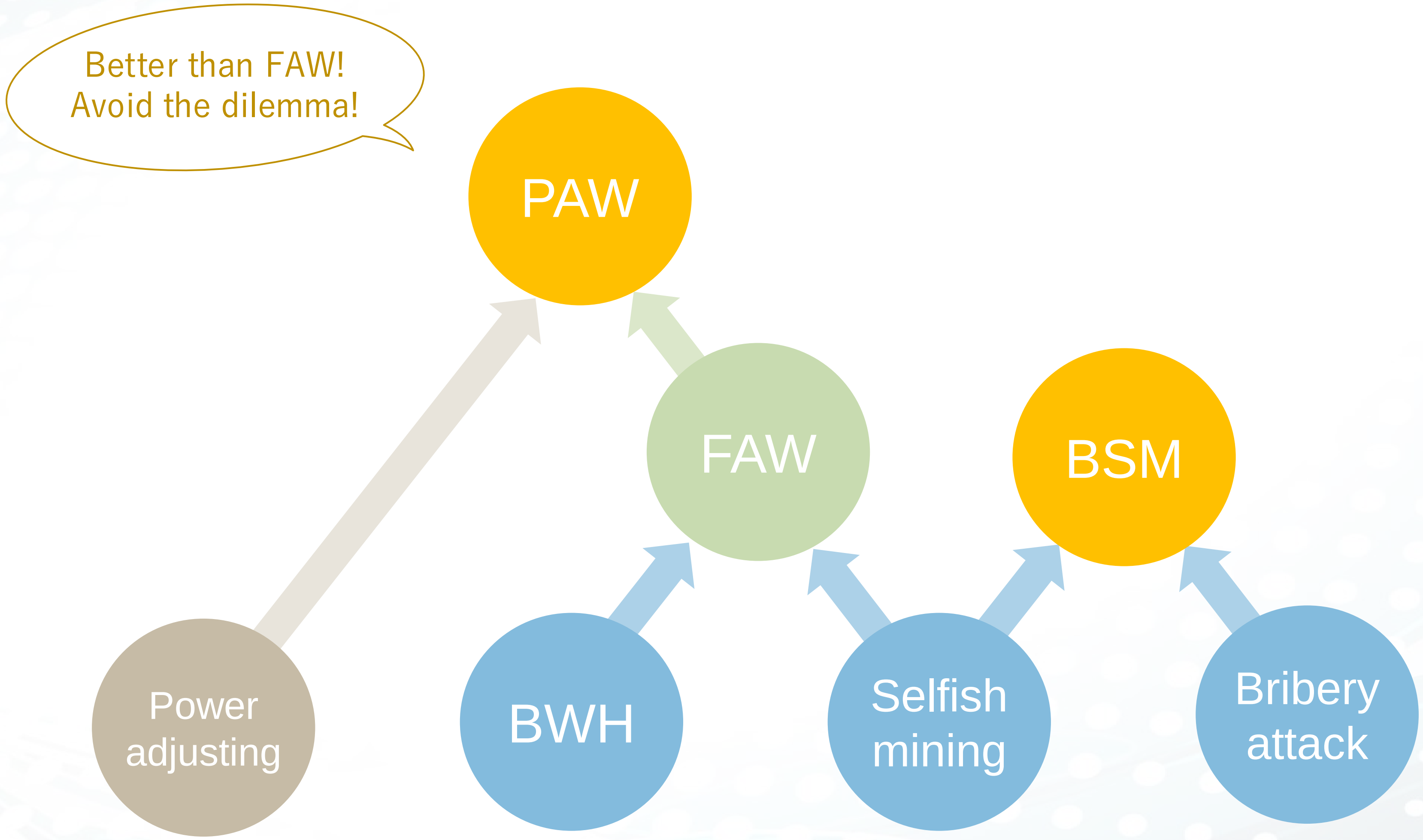


PAW
FAW
BSM
Power adjusting
BWH
Selfish mining
Bribery attack

Conclusion



Better than FAW!
Avoid the dilemma!
PAW
FAW
BSM
Power adjusting
BWH
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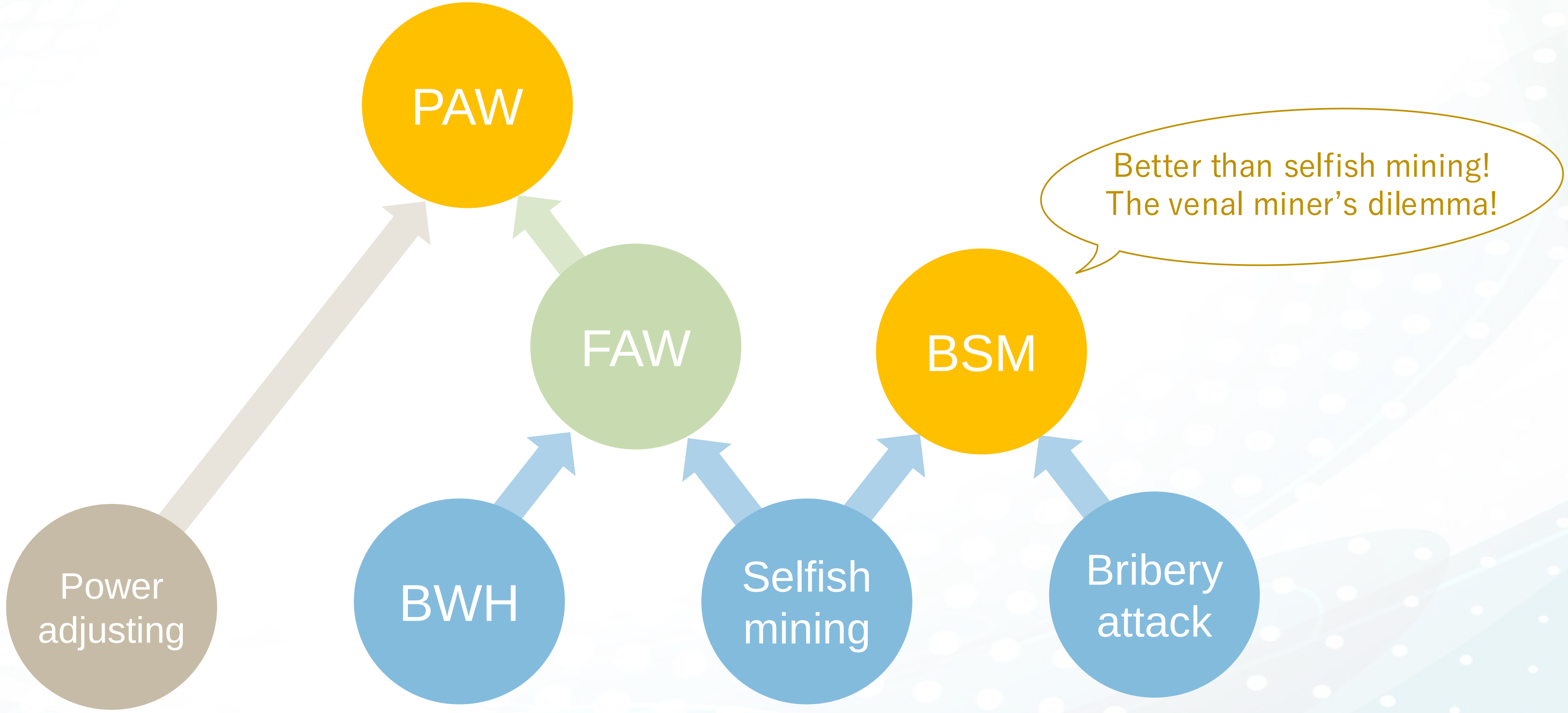
Conclusion


PAW
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Better than selfish mining!
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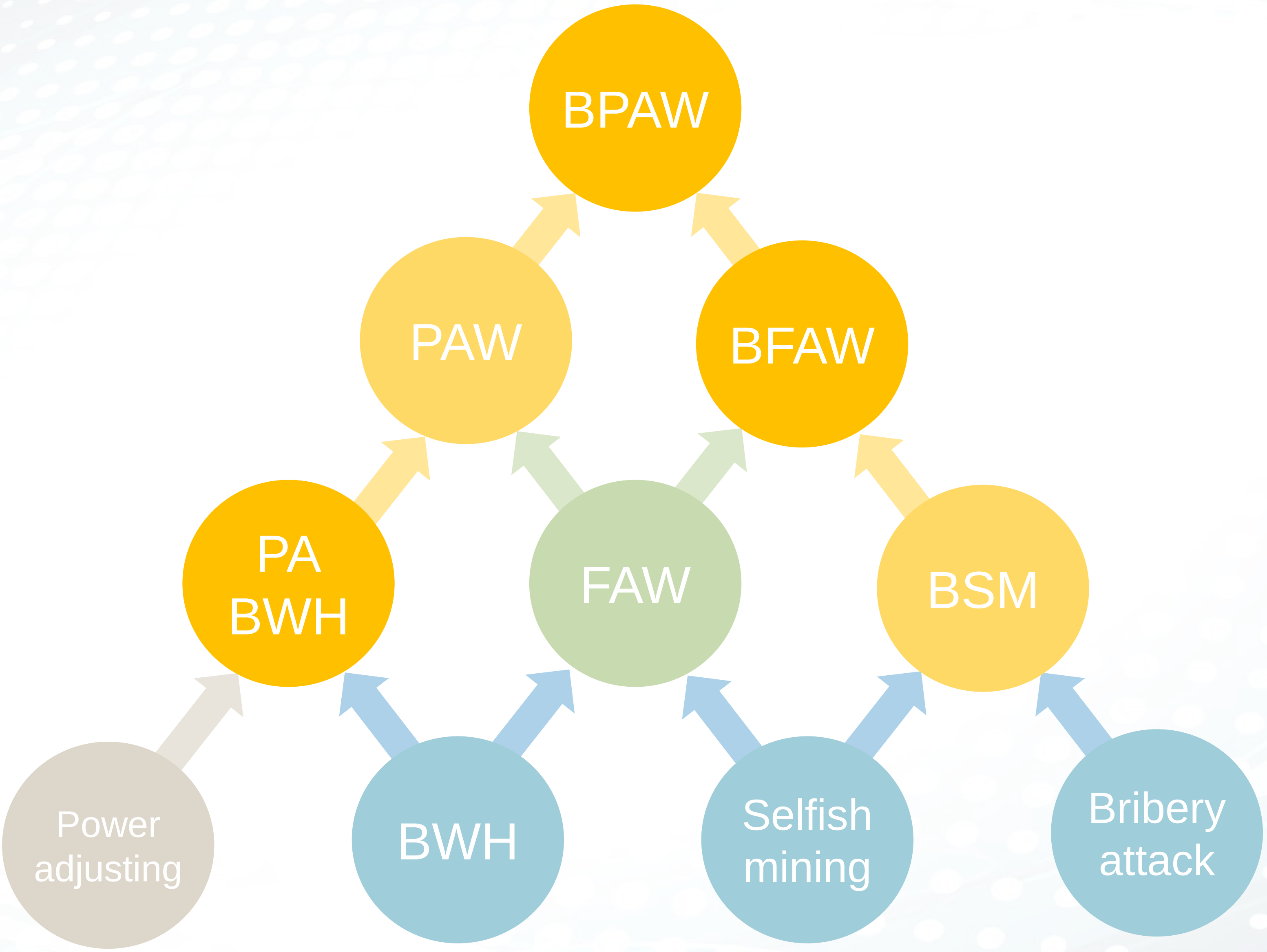
Bribery attack

Conclusion


BPAW
PAW
BFAW
PA BWH
FAW
BSM
Power adjusting
BWH
Selfish mining
Bribery attack

Q&A

THANK YOU