The Road to 5G Adoption: A Network Analysis

By: Kailin Koch
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Abstract

The 5th generational mobile network, otherwise known as 5G, has promised to revolutionize the internet experience with blazing fast speeds. So far, 5G adoption has been slow and halting. In this paper I simulate the impact of speed, product type and network clustering on 5G adoption. I simulate the US mobile market using a network graph, calculate a payoff matrix of 5G and an adoption threshold. I find that current 5G speeds are insufficient to drive network diffusion, though future potential speeds lead to almost a full cascade. 5G home internet and 5G smartphone data demonstrate similar cascades, although 5G home internet has a better payoff given its competitive pricing. Dense clusters in the network without 5G adopters have the potential to block adoption. I end with some recommendations to major carriers based on these findings.

Background

In 2016, the Chair of the Senate Committee on Commerce, Science, and Transportation John Thune delivered a keynote speech, where he declared that “5G isn’t just the next incremental step in mobile speeds; it will be a revolutionary leap forward in wireless capability that will reshape the world around us” (Thune 2016). Policymakers weren’t the only ones who saw the potential of 5G; 5G has been touted as a crucial underlying component of other nascent technology from autonomous vehicles to augmented reality (Finley and Perlstein 2020, Nezami et al 2022).

Yet despite the hype, the rollout of 5G has been slow and halting. Some of this is due to exogenous challenges, such as conspiracy theories that 5G was related to COVID-19 as well as pushback from the FAA about 5G interference with aircrafts (Tiffany 2020, Chokshi 2022). Yet some of the delays in 5G’s rollout has to do with the service’s availability and benefits.

While carriers claim 5G is now available to 230 million Americans, 1 in 3 Americans doesn’t have a 5G compatible smartphone (Abbott 2022, Dellinger 2021b). Additionally, many 5G users and testers have found that speeds are still slower than promised, sometimes even slower than 4G speeds (Dellinger 2021a, Fowler 2020). Similarly, users have found 5G home internet to be glitchy and comparable to cable speeds (Clark 2021).

Research Questions

I wanted to explore how much the actual speed of 5G impacts its speed of adoption. While 5G’s current speeds offer moderate improvements over 4G, the theoretical limit is much higher. Will potential future gains increase the spread of 5G? Additionally, I was curious whether carriers should expect greater adoption from 5G as a smartphone data product or a home internet offering. Finally, I wanted to test Easley and Kleinbergs’ assertion that tight clusters could block diffusion of 5G (Easley and Kleinberg 2010, p577). I will use a graph based approach below to answer these three questions about 5G in the United States:

1. How much does the speed of 5G impact its cascade?
2. Will carriers see greater adoption of 5G smartphone data plans or home internet?
3. Are dense clusters a barrier to adoption of 5G?

Approach

To answer these questions, I create network graphs and explore network coordination games.

5G Adoption as a Coordination Game

Coordination games assume that “if nodes v and w are linked by an edge, then there is an incentive for them to have their behaviors match” (Easley and Kleinberg 2010, p.566). A simplistic implementation assumes there is no payoff if the 2 nodes do not coordinate.

This is not a perfect approximation of the 5G market, but it does have some important parallels. Mobile network purchases are rarely entirely independent purchases. Many Americans share a data plan with other members of their family, and home internet is usually an offering used by an entire household. With 5G, this is even more pronounced. Some of the exciting capabilities 5G offers, like hologram video calls or mixed reality gaming, will require another user to have 5G in order for both to benefit (Verizon 2021, Abril 2022).

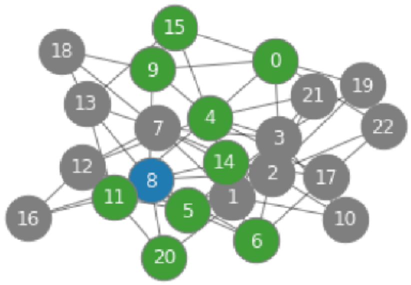
Network Structure

For this network, I used a Barabasi Albert Graph, which has properties found in real world networks, such as short average path length and skewed degree distribution (Barabasi 2014). Additionally, it demonstrates preferential attachment, where newer nodes are more likely to attach to nodes that have more connections (Barabasi 2014).

To mirror 5G’s incomplete footprint in the United States, I set only some of the nodes in the network to have access to 5G. I set this at ~70% of the network, reflecting the proportion of Americans with access to 5G which is somewhere between 50-80% (McKetta 2021, PWC 2021). Nodes can only adopt 5G if they exceed the threshold discussed in the next section AND if they have access to 5G. Without this condition, we would overestimate the diffusion of 5G. 5G access is concentrated in specific geographic areas. Given this, I identified clusters within the graph, and set specific clusters to have 5G access rather than assigning it to random nodes.

The average phone plan has about 3 devices (Dano 2018). As such, I set the number of edges to attach a new node to existing nodes to 3. As the network size increases, there will be nodes with many more than 3 edges. However, this accurately reflects the interconnectedness of large networks.

Diagram 1: Sample Graph
A sample Barabasi Albert graph with n=23 nodes and m = 3 edges.
Green = access to 5G, Blue = early adopter starting node.



Currently, carriers claim approximately 230M Americans have access to 5G (Abbott 2022). I conduct these simulations on a small model to visualize them as well as a larger scale. For each simulation, I set a single “early adopter” who first adopts 5G. In reality, there would be multiple adopters in each graph. However, for simplicity I’ve chosen to simulate a single starting node.

Table 1: Simulation Sizes

Simulation Size	Ratio to Actual Market Size
23	1 : 1,000,000
230	1 : 100,000

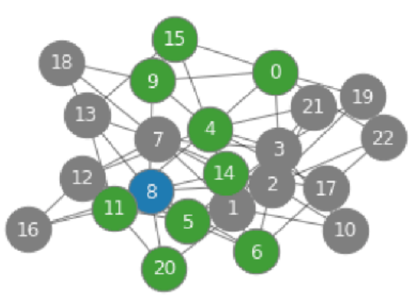
Threshold Model

In traversing this graph, I evaluate a threshold which takes into account the following parameters (Easley and Kleinberg 2010, p567).

- A: The payoff of both players adopting 5G
- B: The payoff of both players retaining 4G
- P: The proportion of p neighbors who have adopted 5G

Nodes adopt 5G at threshold ***q = b / (a+b)***, assuming the node has access to 5G.

Diagram 2: Sample Threshold Update
Assessing whether Node 5 should adopt 5G.
Green = access to 5G, Blue = early adopter starting node.




```
node:  5
p 0.14285714285714285
b/a+b 0.3333333333333333
access to 5g? True
adopt 5g? False
```

Payoff Calculations

To calculate the relative payoff of 5G versus 4G or cable internet, I use the metric of cost per megabyte per second download (Mbps). This allows us to capture both cost and speed. For example, in some cases 5G isn't much faster but it is cheaper. Both of these are important components of the payoff customers see from switching to 5G. I calculate the payoffs of A as the number of times smaller the cost per Mbps is for 5G than the existing 4G or cable internet.

I examine not only the current 5G speeds, but the potential speeds 5G enthusiasts hope it could reach. Many think that 1 gigabyte per second download speeds will be possible as 5G matures, and the theoretical limit for 5G speeds is closer to 10 gigabytes per second. I want to test these values as well to see if they change the diffusion pattern for 5G.

5G Home Internet

Below I compare 3 categories of home internet

- Current state non-5G home internet - from estimates speed and cost of home internet (Morabito 2021, Pew Trusts 2020)
- Current state 5G home internet (As advertised by T-Mobile and Verizon, Paul 2022)
- Potential future speeds of 5G (Edwards and Hoffman 2022)

Table 2: Home Internet Payoffs

	Cost	**Mbps**	**Cost / Mbps**	**Payoff**
Average Non-5G Internet	68	72	$0.94	1
Verizon 5G Home (30M Homes)	50	300	$0.17	6
T-Mobile 5G Home Internet (40M Homes)	50	100	$0.50	2
Weighted Average 5G Home Internet	50	186	$0.36	**3**
Potential - 1GBPS	50	1000	$0.05	**19**
Potential - 10GBPS	50	10000	$0.01	**189**

5G Smartphone Data

Below I compare 3 categories of 4G and 5G phone data

- Current state 4G phone data from testing (Tom's Guide, 2021)
- Current speeds of 5G phone data from testing (Tom's Guide, 2021)
- Potential future speeds of 5G (Edwards and Hoffman 2022)

Note: currently all the major carrier plans include 5G. As such, the price difference is the same for 4G versus 5G

Table 3: 5G Smartphone Data Payoffs

	4G			5G			
	Cost	*Mbps*	*Cost / Mbps*	*Cost*	*Mbps*	*Cost / Mbps*	*Payoff*
AT&T	65	37	$1.75	65	76	$0.86	2
T-Mobile	60	36	$1.65	60	71	$0.85	2
Verizon	70	53	$1.31	70	67	$1.04	1
Average	65	42	$1.54	65	71	$0.92	**2**

	4G			Potential 5G - 1Gbps			
	Cost	*Mbps*	*Cost / Mbps*	*Cost*	*Mbps*	*Cost / Mbps*	*Payoff*
AT&T	65	37	$1.75	65	1000	$0.07	27
T-Mobile	60	36	$1.65	60	1000	$0.06	28
Verizon	70	53	$1.31	70	1000	$0.07	19
Average	65	42	$1.54	65	1000	$0.07	**24**

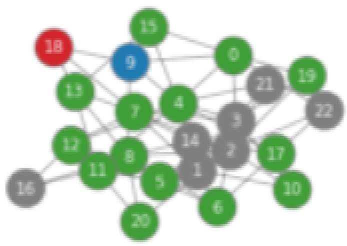
	4G			Potential 5G - 10Gbps			
	Cost	*Mbps*	*Cost / Mbps*	*Cost*	*Mbps*	*Cost / Mbps*	*Difference*
AT&T	65	37	$1.75	65	10000	$0.01	270
T-Mobile	60	36	$1.65	60	10000	$0.01	275
Verizon	70	53	$1.31	70	10000	$0.01	188
Average	65	42	$1.54	65	10000	$0.01	**237**

Results

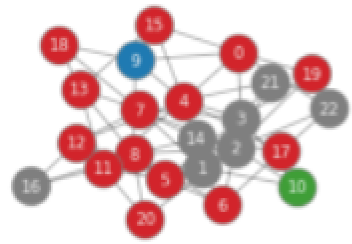
Figures 3 - 8: End State of 5G Adoption Simulations for n = 23 Size Graphs
green = access to 5G, red = adopt 5G, blue = early adopter starting node

5G Home Internet

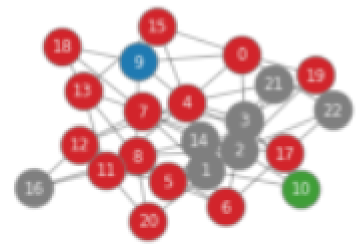
Current 5G (a=2, b=1)



Potential 5G (a=24, b=1)

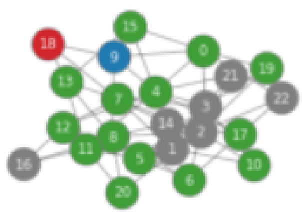


Potential 5G (a =237, b=1)

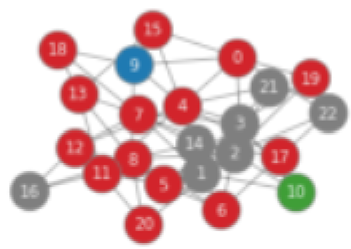


Smartphones

Current 5G (a=3, b=1)



Potential 5G (a=19, b=1)



Potential 5G (a =189, b=1)

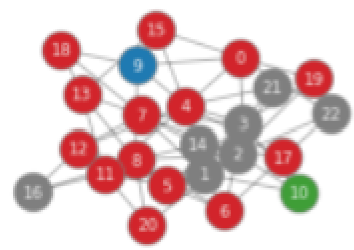


Table 4: Results for 12 Simulations

	Current 5G		Potential - 1Gbps		Potential - 10Gbps	
5G for Smartphone Data						
Graph Size	*n=23*	*n=230*	*n=23*	*n=230*	*n=23*	*n=230*
# 5G Access	16	175	16	175	16	175
# 5G Adopt	2	2	15	169	15	169
# Adopt	13%	1%	94%	97%	94%	97%
Full Cascade?	N	N	N	N	N	N
5G Home Internet						
# 5G Access	16	175	16	175	16	175
# 5G Adopt	2	2	15	169	15	169
# Adopt	13%	1%	94%	97%	94%	97%
Full Cascade?	N	N	N	N	N	N

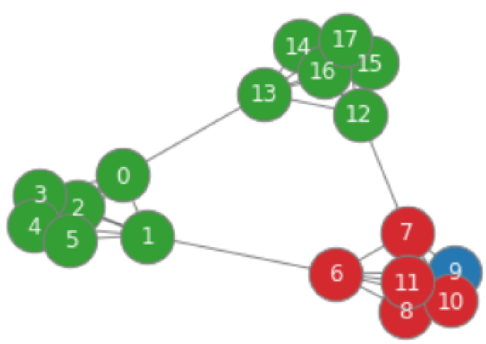
Clustering

Easley and Kleinberg posit that if a node is in a denser cluster than 1-q, the node will not adopt (Easley and Kleinberg 2010, p.575). Clustering is a known phenomenon for 5G, with access and adoption currently concentrated in major cities. I was curious if 5G adoption may be slowed by dense concentrations of non users, whether these are cities without 5G access, college campuses in rural areas or military bases.

To answer this research question, I loosened some of my assumptions from my previous testing. Rather than utilize a Barabasi-Albert graph, I opted for a Ring of Cliques. This produced more dense clusters, a key attribute for testing this phenomenon. Secondly, I assumed every node had access to 5G. Otherwise, it would be hard to tell if the spread stopped because of the dense cluster or the lack of 5G access. I selected arbitrary payoffs of a = 2 and b =1, rather than drawing from real values as before.

Figure 4: Clustering Cascade

green = access to 5G, red = adopt 5G, blue = early adopter/start node




```
node:  12
p 0.16666666666666666
b/a+b 0.2

1-q 0.8
cluster_density 0.8333333333333334
density > 1-q? True
adopt 5g? False
```

Here we see adoption spreads through the bottom cluster. However, when it tries to spread to the next cluster via node 12, it fails to do so because the cluster density >= 1 - q. This aligns with Easley and Kleinbergs' assertion that if a network does not have a full cascade, at least one of the remaining clusters has a density greater than 1-q (Easley and Kleinberg 2010, p.575).

Analysis

These results show some quintessential elements of networks. First, there is a tipping point, or two different equilibria for 5G adoption (Easley and Kleinberg 2010, p.517). This is evident between the current and potential 5G speed simulations, where the network goes from virtually no diffusion to almost a complete cascade. Secondly, neighbor adoption has a strong influence on whether a node chooses to adopt. For example, in the initial simulations node 10 never adopts 5G, even though it has access (see page 7). This is because none of its neighbors have access to 5G and thus none adopt.

While news has focused on the smartphone data applications of 5G, the payoff analysis demonstrates that 5G home internet actually offers a higher payoff to consumers (a=3 versus a =2). This is because 5G home internet is not only faster than cable, it's also noticeably cheaper.

The simulations are identical for home internet and smartphone data, although the payoffs are different. In both cases, the current payoff of 5G is not enough to cascade through the network beyond the early adopter and a single additional node. This aligns with the rollout so far, which has not spread to most US consumers (Dellinger 2021a).

In contrast, if 5G speeds reach 1Gbps, the diffusion goes to almost every node with access to 5G. There is no difference between 1Gbps and 10Gbps. Intuitively this makes sense, as after a certain point fast 5G is "fast enough" and there is diminishing number of consumers that will newly adopt 5G.

Lastly, clustering poses a real threat to 5G adoption via network diffusion. Dense clusters will be an obstacle to adoption if there are no early adopters in these communities.

Research Questions, Revisited

How much does the speed of 5G impact its cascade?
The speed of 5G has a major impact on adoption. Today's performance, only slightly better than the existing technology, is not enough for 5G to diffuse through a network. Add on the uneven footprint of 5G, and there are even more obstacles to adoption.

Will carriers see greater adoption of 5G smartphone data plans or home internet?
Both show similar cascade effects. However, 5G home internet's more competitive payoff could be a major advantage as speeds increase. This is also an entirely new line of business for many of the major carriers, making it an additional revenue stream rather than smartphones which will largely supplant their existing market.

Are dense clusters a barrier to adoption of 5G?
Yes, clusters are a barrier to 5G adoption. Again, this problem is compounded by the fact that many clusters, particularly rural populations, have no access to 5G at this point.

Recommendations to Carriers

1. **Continue investing in faster 5G:** This research demonstrates that without a bigger benefit in either speed or price, there is not enough natural momentum to motivate a switch to 5G. The good news is there are 3 levers the carriers can explore in the interim to increase the network cascade. First is the price. Perhaps while the speeds are comparable with 4G, the carriers can offer more competitive pricing to drive up the payoff. Alternately they can focus on bringing up high speeds while keeping costs the same to bring up the payoff. Lastly they can try and seed more early 5G users in cities with 5G access, which can also help drive diffusion through their networks.

2. **Don't neglect 5G home internet:** While often not the focus of major carrier marketing, 5G home internet offers an opportunity for wireless carriers to compete with cable giants, some of Americans most hated companies (Gibson 2018). Additionally the payoff is higher than for 5G smartphone data given the lower pricing relative to non-5G options. This should not be forgotten in the push for 5G smartphone data adoption.

3. **Prioritize connected early adopters**: To mitigate the effects of dense clusters which may slow the network cascade, identify key individuals in networks that are not using 5G. This can help prevent diffusion stalling when insulated communities don't have enough adopters in their network to exceed the threshold (Easley and Kleinberg 2010 p572).

Potential Future Work

There are a number of simplifications I have made in creating these simulations. First, I am initializing a single early adopter, rather than multiple. Second, I am only considering the cost of a data plan, not a 5G compatible device. Third, I consider payoffs to only happen with coordination, but there are benefits from 5G without any coordination, such as faster movie download speeds. Lastly, I consider a point estimate for 5G speeds, but 5G speeds range widely depending on location.

To build on this analysis I would:

- Seed multiple early adopters
- Create a coordination game with payoffs without coordination (a,b and b,a) to capture the benefits of 5G for an independent individual
- Vary the payoff based on a range of 5G speeds
- Create a weighted graph to simulate the impact of decision makers for households

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